

The effect of urban runoff on the water quality of the Sweetbriar Brook, Ampthill, UK

Dagvattnets effekt på vattenkvaliteten i Sweetbriar Brook, Ampthill, Storbritannien

Anna Krafft



Examensarbete (Master Thesis)

Handledare (Supervisors): Stig Ledin & Sean Tyrrel

**Sveriges Lantbruksuniversitet
Institutionen för markvetenskap
Avdelningen för hydroteknik**

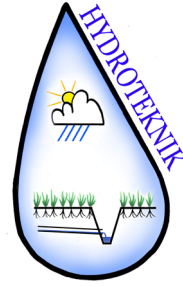
**Rapport 1
Report**

**Swedish University of Agricultural Sciences
Department of Soil Sciences
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MSc Thesis

Fulfilled in cooperation between Cranfield University at Silsoe & Swedish University of Agricultural Sciences

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PREFACE

This thesis was made in cooperation between the british Cranfield University at Silsoe and Swedish University of Agricultural Sciences (SLU). It fulfills the requirements for degrees at both universities, in agronomy at SLU and for a Master of Science in Water Management at Cranfield University.

I would like to express my gratitude to a number of people, without whom, this thesis would not have been completed.

My warmest thank you to Sean Tyrrel, my main supervisor, who has given me invaluable help throughout this project, who always has had time to discuss the work and answer questions! I would also like to thank the rest of the Tyrrel family for letting me invade their garden with the automatic sampler. The garden of the Hess family was also used for data collection in this study, thank you for letting me have the rain gauge on your lawn! A special thanks to Tim Hess, who suggested this project to me, and having been helpful in answering questions, too. Thank you also to my supervisor Stig Ledin for having been supportive and interested, even from the other side of the North Sea!

I would like to thank the laboratory technicians in the Soils lab and the NSRI lab, and lab manager Gabriela Lovelace, for always having taken time to help me and to answer any question. Thank you also to department technician Ian Seymour, who in always good spirit has helped me install and remove sampler and rain gauge.

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LIST OF ABBREVIATIONS

BOD	biochemical oxygen demand
cfu	colony forming units
COD	chemical oxygen demand
DO	dissolved oxygen
dw	dry weight
FOG	fats, oils and grease
FTU	Formazin Turbidity Units
MBDC	Mid-Beds District Council
SS	suspended solids
tot-Fe	total iron
tot-N	total nitrogen
tot-P	total phosphorus
tot-Zn	total zinc
WFD	Water Framework Directive

ABSTRACT

The Sweetbriar Brook, a small watercourse in Ampthill, Bedfordshire, in a mainly residential catchment, was studied. The scope was to characterise the water quality during low flow conditions and storms, by chemical analyses of dissolved oxygen, turbidity, metals, nutrients, oil and thermotolerant coliform bacteria, among others. A baseline series of analyses from five sampling points along the stream was undertaken during spring-summer 2005. One storm was sampled in short time intervals at the most downstream sampling point. Rainfall volumes and intensities were recorded nearby.

The water quality at baseline conditions was generally good. One exception was thermotolerant coliforms, which were occasionally very high, posing a health risk to children playing in or near the water. Another exception was nutrients, especially phosphorus was exceeding guideline values at some locations. Iron occurred in elevated levels in the groundwater and seemed to dissolve in standing water with oxygen depletion. The runoff did generally not carry higher pollutant concentrations than expected for this catchment, except for coliforms, which were dramatically high in some samples. An interesting observation was that not only one first flush, carrying most pollutants, occurred, but subcatchments with different times of concentration gave rise to individual pollutant peaks. Flooding was a problem in this catchment, retro-fitting a sustainable urban drainage system is hence recommended.

Sediment analyses of total zinc and thermotolerant coliforms were also undertaken, as a complement to the water analyses, showing relatively high zinc concentrations, increasing with depth. Coliforms were fewer than expected from the numbers in the water and demonstrated no consistency in sampling points or depths.

No statistical tests were undertaken, as more sampling points and variables were prioritised over replicate samples. This is however a drawback in the interpretation and reliability of the results. More sampling, both chemical and biological, is needed to verify the results.

Key words: runoff, water quality, catchment, thermotolerant coliform bacteria, nutrients, rain, first flush, Sustainable Urban Drainage System (SUDS), sediment

Krafft, A. 2005. *The effect of urban runoff on the water quality of the Sweetbriar Brook, Ampthill, UK*. Master thesis. Cranfield University & Swedish University of Agricultural Sciences. Uppsala. 2005.

REFERAT

I detta projekt studerades det lilla vattendraget Sweetbriar Brook i Amptill, Storbritannien. Vattenkvaliteten under låga flöden, samt vid regn, undersöktes med hjälp av kemiska analyser av bland annat löst syre, turbiditet, metaller, närsalter, olja och termotoleranta coliforma bakterier. Vattenprover togs vid fem punkter längs bäcken under våren och sommaren 2005. Ett regnväder provtogs kontinuerligt under korta tidsintervall vid provpunkten längst nedströms. Regnvolym och -intensiteter registrerades också.

Vattenkvaliteten under bakgrundsförhållanden var generellt god. Ett undantag var termotoleranta coliformer som tidvis var mycket höga och då utgör en hälsorisk för barn som leker i eller nära vattnet. Ett annat undantag var närsalter, särskilt fosfor översteg rekommenderade gränsvärden vid några provpunkter. Järn förekom i förhöjda halter i grundvattnet och verkade lösas ut i stillastående syrefattigt vatten. Avrinningen förde generellt sett inte med sig högre föroreningskoncentrationer än väntat för den här typen av avrinningsområde, med undantag för coliformer som förekom i dramatiska halter i vissa prov. En intressant observation noterades angående smutspulsfenomenet first flush, där den största delen av föroreningarna vanligen sköljs bort med den tidigaste avrinningen. I det här avrinningsområdet tycktes istället flera underavrinningsområden med egna smutspulser förekomma, som ger flera föroreningsstoppar. Översvämning var också ett problem längs bäcken, därför rekommenderas implementering av ett system för lokalt omhändertagande av dagvatten.

Sediment analyserades med avseende på total-zink och termotoleranta coliformer som ett komplement till vattenproverna, och visade på relativt höga zinkkoncentrationer som ökade med djupet. De coliforma bakterierna var färre än väntat, jämfört med halterna i vattnet, och visade heller inga samband mellan provpunkter eller djup.

Inga statistiska test genomfördes eftersom fler provpunkter och fler analysvariabler prioriterades högre än insamling av replikata prov. Detta är emellertid en svaghet i tolkningen och tillförlitligheten hos resultaten. Mer provtagning, både kemisk och biologisk, behövs för att verifiera dessa resultat.

Nyckelord: dagvatten, vattenkvalitet, avrinningsområde, termotoleranta coliforma bakterier, närsalter, regn, first flush, lokalt omhändertagande av dagvatten, sediment

Krafft, A. 2005. *The effect of urban runoff on the water quality of the Sweetbriar Brook, Amptill, UK*. Master thesis. Cranfield University & Swedish University of Agricultural Sciences. Uppsala. 2005.

1 INTRODUCTION

This thesis concerns water quality and the effects urban runoff can have on it. The Sweetbriar Brook, a small watercourse in Ampthill, Bedfordshire, was chosen as the study site. One of the reasons for this watercourse to be examined was to provide new information on the runoff effects on the water quality in a small urban catchment in a mainly residential area. Most stormwater projects in developed regions have been carried out in areas of higher pressures, such as industrial sites, highways and dense urban regions, where pollution in the runoff often is considerable. An examination of this small catchment would make an interesting comparison, and bring to light if substantial pollution also can occur in such a catchment and watercourse. Another reason for choosing the Sweetbriar Brook was that some hydrological and spatial information recently was collected (Hess & Tyrrel, 2004), that aided in the characterisation of the area and the behaviour of the watercourse.

This thesis begins with a literature review with background information on runoff, sediments, pollution and stormwater treatment. A catchment description and the expectations on what might be found, lead to the aims and objectives of the project. The thesis then presents the practical work carried out, and finally the results along with their interpretations and recommendations.

2 LITERATURE REVIEW

This literature review provides a background for the sources and types of pollutants found in stormwater and sediments, together with some views on the need for treatment of the runoff.

2.1 Runoff

Runoff, or stormwater, is rainfall travelling over the ground surface before infiltrating or reaching a recipient. It brings pollutants and other compounds from the surfaces it crosses, which is particularly a problem in urban areas with impermeable surfaces, but should not be neglected in rural regions either. The composition of the runoff is mainly due to the types of surfaces it drains off, the antecedent dry period and the original pollution load in the rainfall (Larm, 1994). The quality of the runoff hence varies in both space and time. Urban areas hold more compounds than rural areas, due to the lower infiltration capacity and more polluting activities in urban regions. More pollutants accumulate and are washed off after long dry periods. There is a clear pattern, called the first flush, showing that most of the substances are removed with the first part of the rain. Ellis (1991) refers to research (Thornton & Saul, Geiger) showing that most non-soluble pollutants are up to 65% washed off with the first 50% of the runoff volume. Also soluble pollutants tend to have significant removal during the initial runoff. The first flush pattern is of course also related to the rainfall intensity, the hydrological characteristics of the catchment and the temporal pattern of the storm (Ellis, 1991). Higher intensity rains have a greater ability to detach pollutants from ground surfaces and to move particles that often have pollutants adsorbed to them, giving higher pollution concentrations in the runoff (Luker & Montague, 1994; Larm, 1994).

The first flush is a sign of short-time variation in runoff, but there are also many long-time variations. The pollution loads over the months are highest during autumn and winter when rainfalls generally are higher. The greatest pollution concentrations are found in runoff from heavy summer storms and in snowmelt (Larm, 1994).

2.2 Pollution

This section presents sources and types of pollution, and some typical concentrations in runoff from different environments. The sources and types are summarised in Table 2.1. Some comments on specific pollutants are given in Table 2.2.

Table 2.1 Summary of sources and types of pollutants

Sources	Pollutants
Human activities such as heating, traffic and industry → atmospheric pollution and fallout	Heavy metals, N, P and others
Traffic: -Vehicles → fuel emissions, abrasion, corrosion -Roads and road equipment → abrasion and corrosion -De-icing activities → road salt	SS (suspended solids), heavy metals (Cd, Cu, Pb, Zn, Fe), organic compounds The salt itself with chlorides, and small amounts of chromium, nickel and cyanides
Buildings → particles of brick, concrete, glass and paint	
Animal faeces and urine	Bacteria, viruses and particles with a high biochemical oxygen demand (BOD), N, P
Plant debris and fallen leaves	Particles and higher BOD
Pesticides	Organic compounds

(Sources: Butler & Davies, 2000; Campbell *et al*, 2004; Harrison, 1990; Larm, 1994; Luker & Montague, 1994; Salomonson, 2002)

Table 2.2 Comments on specific pollutants in stormwater

Pollutants	Comments
Organic compounds	In fuels, exhaust fumes, tyres, pesticides, paint and solvents
-Oil	In vehicle emissions, petrol stations and garages. Toxic and harmful
Suspended solids (SS)	From arable land, erosion, construction, tyres and road surfaces
Heavy metals	Harmful or toxic, although traces of some are essential. Most common in the particulate phase in stormwater
-Zn	Ubiquitous in road equipment and vehicle industry
-Fe	Essential element, high concentrations in water cause discolouration, taste and odour problems
Nitrogen (N) and phosphorus (P)	Cause eutrophication, and N also acidification

(Sources: Butler & Davies, 2000; Campbell *et al*, 2004; Harrison, 1990; Larm, 1994; Luker & Montague, 1994; Salomonson, 2002)

The pollution concentrations of runoff vary greatly. Table 2.3 presents concentrations of some pollutants in runoff from various sources.

Table 2.3 Pollution concentrations in runoff from three different sources given in mg/l or cfu/100 ml for thermotolerant coliforms, shown as average value and (min-max)

Constituent	Runoff, general	Residential, houses	Car parks
BOD	14 (8-30)		
COD	65 (50-100)	70 (40-80)	(100-200)
Tot-N	2 (1.3-3.6)	1.8 (1.0-2.0)	
Tot-P	0.3 (0.1-0.76)	0.3 (0.2-0.6)	
Pb	0.2 (0.005-0.84)	0.1 (0.03-0.17)	(0.03-0.3)
Cu	0.1 (0.0015-0.84)	0.05 (0.014-0.1)	(0.03-0.1)
Zn	0.3 (0.005-0.95)	0.2 (0.07-0.3)	(0.1-0.4)
Cd	0.001 (0.0005-0.003)		(0.002-0.004)
Ni	(0.005)	(0.011)	
SS (suspended solids)	200 (30-1750)	(50-150)	(20-150)
Oil	0.4 (0.4-3.3)	(0.2)	high
Thermotolerant coliforms (given as cfu/100 ml)	400,000 (210,000-640,000)		

(Source: Larm, 1994)

2.3 Sediments

Sediments are important when discussing runoff and pollution, since many substances are adsorbed to the sediment particles and therefore accumulated on, and/or transported with them. Sediments can be either deposited or suspended, depending on the particle size. Deposited sediments can be resuspended by strong currents. Sediment sources are mainly the same as pollutant sources discussed in the section above, with the addition of wash-off from adjacent areas, vegetation, intrusion of soil around pipes and gullies, and industrial and commercial activities (Butler & Clark, 1995).

Sediments are however also important in element cycling in rivers and lakes, since nutrients are also attached and transported. Bacteria can also accumulate in the river bed, surviving for longer times than in the water phase, posing a potential health risk if resuspended (Ellis, 1991).

2.4 The need for treatment of urban runoff

As shown above, a lot of pollution is coupled with urban runoff. The protection of good water quality is one reason for treating the stormwater, but there are others as well, presented in this section. Health and safety is one important argument, especially since people and property are mainly located in the urban areas. Stormflows can cause flooding, putting lives and properties at risk, making the treatment a socio-economic issue as well. The temporal unpredictability of stormflows and the dramatic volumes they can bring demand a safe and efficient drainage, but an adequate treatment must also be planned for. It is well known that urbanisation with increased impervious areas increase the quantity and intensity of the runoff, and reduce the quality. The hydrograph peak also comes earlier, due to the faster travel over the hard surfaces (Cook, 1998; Campbell *et al*, 2004). Enough channel capacity is therefore important, as well as sufficient storage at the treatment site.

Catchment planning is important for solving many of the runoff-related problems. The importance of catchment planning is likely to increase with the implementation of the EU Water Framework Directive (WFD), when stricter requirements for good water quality will be applied. Despite improvements in water quality, there will however always be a need for runoff treatment, due to the runoff behaviour in urban areas. Larm (1994) states that rapid short-time variations are very stressful for flora and fauna, which implies that attenuation and short-term storage facilities are necessary aids for aquatic communities. It is thus obvious that treatment is vital, both for quality and quantity reasons.

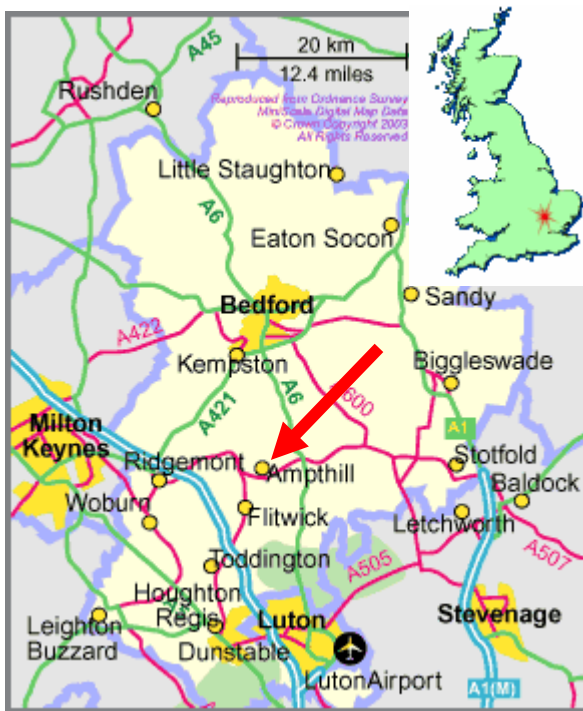
2.5 Sustainable urban drainage systems

One solution to the requirements for treatment and flow attenuation mentioned above is sustainable urban drainage systems (SUDS), which is a concept where surface runoff quantity and quality are regarded equally to the amenity value of the water in urban areas. The runoff shall be attenuated and treated as close to the source as possible, as this reduces the risks of flooding and pollution. Many types of source control structures are available (CIRIA, 2001). Most SUDS are constructed during new development, but it is important to implement them in existing urban areas as well, to reduce impacts of diffuse pollution (Mitchell, 2005). Studies describing such retro-fitting are found in e.g. Villareal *et al* (2004) and Jeffries

(2001). SUD systems may well be mixed to achieve the most appropriate function, for example attenuating flow, reducing flood risk and also reducing pollution. They will also help to achieve the water quality requirements of the WFD.

3 CATCHMENT DESCRIPTION

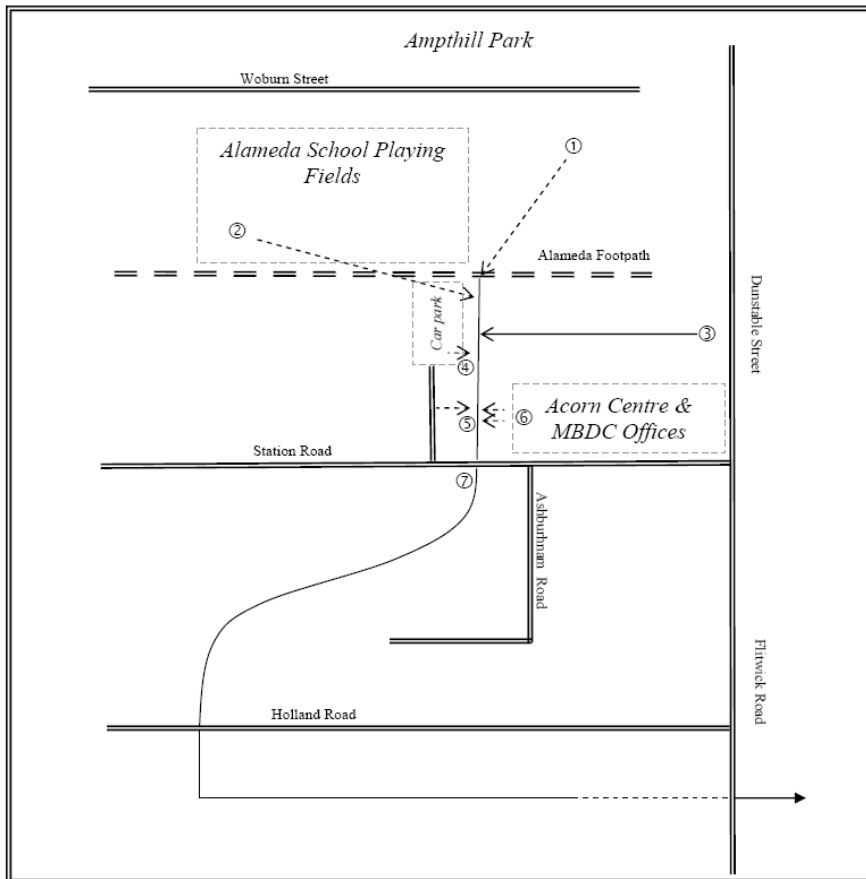
The catchment and hydrology of the Sweetbriar Brook is presented in this section. The brook is located in the town of Ampthill, Mid-Bedfordshire, see Figure 3.1. The catchment is small (1-2 km²) in a mainly residential area, but schools, administrative buildings with car parks, and a playing field are also parts of the catchment. Only the first 400 m of the brook was studied in this project.



(After Tourist net UK, 2005; iDreams, 2005)

Figure 3.1 Location of Ampthill in the UK.

The geology underlying Ampthill is the Cretaceous formation the Woburn Sands on Ampthill clay. The Woburn Sands constitutes the Lower Greensand aquifer and is ferruginous, giving the groundwater elevated iron levels (British Geological Survey, 1994). Groundwater from the aquifer feeds the Sweetbriar Brook, but it also receives water from runoff. A scoping study for flood management has been undertaken by Hess & Tyrrel (2004), where the hydrology of the brook was identified. The information in the rest of this section is taken from this study. The watercourse starts with two pipes in a headwall, see Figure 3.2, although it originally reached another 100 m to the north. The Alameda playing field and impervious areas north and east of it are now drained by pipes into the brook. It then runs straight for almost 400 m along a tree-lined pathway until Station Road. Along this part, a number of pipes carry runoff from adjacent mostly impervious areas. The project was undertaken along this first reach. From Station Road the brook first follows the contour at the side of the valley, before diverting from it and flowing several metres above the valley bottom level. After passing under Holland Road, the brook turns sharply to the east and becomes the Blackwaters drain. It runs for almost 200 m and then drops into a long culvert passing under Flitwick Road, having by then returned to the natural valley. What happens to it after the Flitwick Road culvert is unclear.



(After Hess & Tyrrel, 2004)

Figure 3.2 Schematic representation of the Sweetbriar Brook with hydrological inputs shown.

The inputs of water to the brook are described below and shown in Figure 3.2.

- 1) Headwall pipes, with groundwater and drainage water, probably from the Alameda playing field. During dry weather, water only flows in the lowest pipe. The average flow was measured between June-July 2004 to 0.012 l/s, with some water also leaking around the lower pipe.
- 2) Side perforated drain, which seems to collect drainage from the Alameda playing field with an average flow of 0.70 l/s. It carries flow at all times, with no increase during rain events.
- 3) Lyme Road tributary, that joins the brook some 112 m from the headwall, bringing runoff from The Pines and Lyme Road.
- 4) School car park gully. A pipe from the Alameda Middle School car park carries substantial runoff during storms.
- 5) Pipe from school access road. A pipe from the access road to Firs Lower School and Alameda Middle School carries substantial runoff during storms.
- 6) Council car park drainage pipes, there is no flow during dry weather from the two pipes, but heavy runoff during storms.
- 7) Station Road gullies; three gullies drain Station Road into the brook. Substantial road runoff flows down the road during storms, and the gullies cannot cope, making the water flow over the edges into the brook on both sides of the culvert, also flooding the footpath.

The hydrological behaviour of the brook varies a lot between dry weather and storms. During dry spells there is baseflow from the headwall and side perforated drain, with the addition of various seepages. The observed baseflow downstream of the Station Road culvert was estimated to be 2.5 l/s. During storms, however, the peak flow was measured to more than 80 l/s. The catchment behaviour is flashy and the drains and pipes respond with runoff within 15 minutes of the start of the rainfall, but the runoff also decreases quickly after the storm. The carrying capacity of the brook at the Station Road culvert is calculated to a 1 in 100 year peak flow of more than 1000 l/s, if the culvert screen is not blocked, which is the normal case. Even after debris removal it rapidly blocks again. Regular maintenance of the channel, and especially the weed screen, was identified as important for managing the flood risk, together with a more long-term solution, like retro-fitting a SUD system (Hess & Tyrrel, 2004).

4 WATER QUALITY EXPECTATIONS

The pollution load in the Sweetbriar Brook is difficult to forecast. Most studies have previously been carried out in more heavily polluted urban areas, or in rural areas to identify diffuse pollution. This catchment represents an area without obvious significant inputs of pollution, although car parks and schools with access roads are likely to carry traffic-related pollutants. The watercourse is very small, which also seems uncommon in studies. Although residential areas generally have lower pollution concentrations than areas with more traffic, e.g. car parks (see Table 2.2), traffic-related pollutants are likely to be found in the watercourse. Pollutants from faeces and urine from pets and wild animals are also expected, since the path along the brook is popular for dog-walkers, and where wild animals also are seen.

Impermeable surfaces cause more and faster runoff, as identified in many studies (e.g. Larm, 1994). This catchment also has many permeable surfaces, but the storm response still is very flashy, according to Hess and Tyrrel (2004). The baseflow is expected to carry only low concentrations of pollutants such as heavy metals, BOD and thermotolerant coliforms. The storm flow is however likely to carry high levels of all pollution types, since a wash-off of especially impermeable surfaces occur. The actual load mainly depends on the rainfall amount and intensity and the antecedent dry period, and can therefore not be predicted. The first flush pattern is also expected in the storm analyses.

The characteristics of the under-lying Woburn Sands are likely to be noticed in the iron analyses of the groundwater-fed pipes discharging into the brook, as the ferruginous sands give elevated iron concentrations in the groundwater (British Geological Survey, 1994). Since much of the Woburn Sands area is agricultural where fertilisers are used, there might be elevated concentrations of nitrogen in the groundwater as well.

The sediment is also likely to contain deposited particle-associated pollutants and thermotolerant coliforms. The pollutants resuspended during storms are likely to increase the storm-associated pollution.

This study will give an example of the types and concentrations of pollutants such a small urban catchment contributes with during storms, and also the levels the low flows carry. The sediment study will show the amounts of some particle-bound pollutants that together with the water analyses will give an indication of the presence of pollution and the health and safety risk the watercourse might pose.

5 AIMS AND OBJECTIVES

The aims and objectives were identified as:

- To investigate the water quality of the brook, with relation to parameters such as N, P, heavy metals (Zn), BOD, conductivity, turbidity and thermotolerant coliform bacteria.
- To state what types of pollutants the water carries, at base flow and at rain events, after runoff addition.
- To investigate the impact of stormwater on the brook.
- To analyse thermotolerant coliforms in the sediment, originating from e.g. dog or bird faeces, possibly posing a health hazard to children playing in the water.

6 METHODOLOGY

This section presents the sampling and analyses procedures for the data collection. The effects of urban runoff on the Sweetbriar Brook were studied by three types of samplings, two for water and one for sediment. A baseline longer-term sampling for the water quality commenced in April 2005, and served as a background comparison for the storm sampling, undertaken during a summer storm in June 2005. A small sediment sampling completed the practical work.

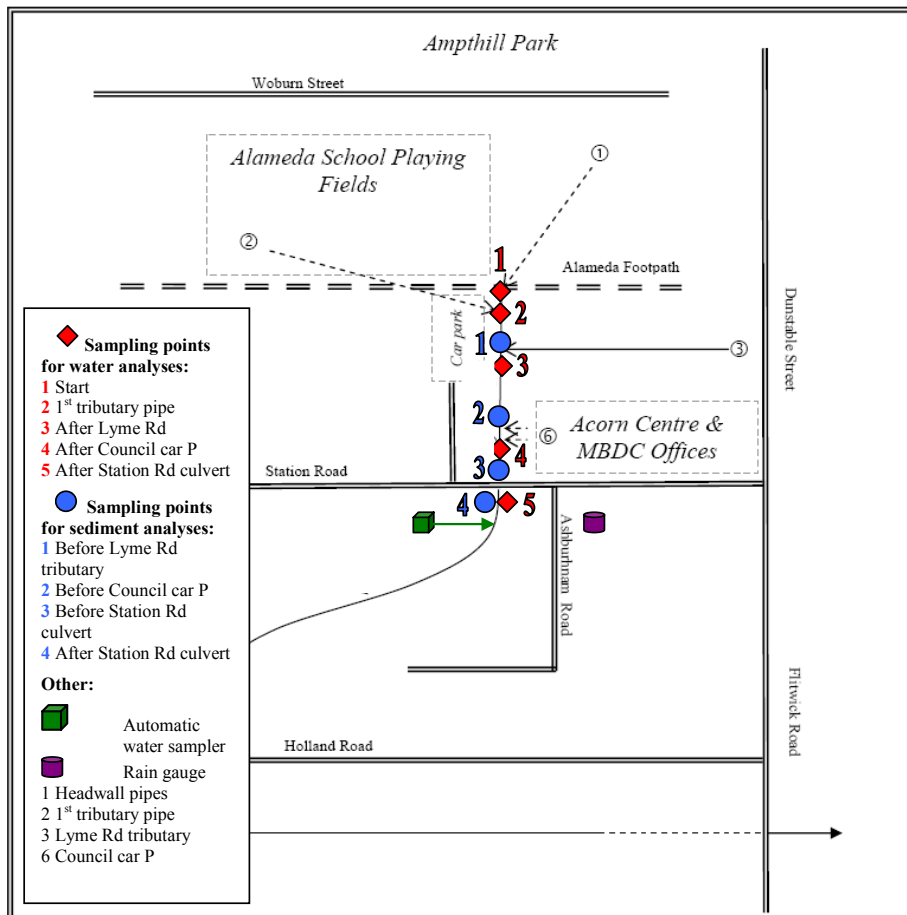
6.1 Baseline sampling

This section describes the sampling points, the reasons for them to be chosen and the times for sampling. Five points were selected for the baseline sampling, see Figure 6.1:

- 1) The lower headwall pipe where the brook starts
- 2) The first tributary pipe with a constant flow
- 3) After the Lyme Road tributary
- 4) After the Council car park
- 5) After the Station Road culvert

The first two points were chosen to show the initial water quality, which also reveals some of the groundwater quality. The third and fourth points were selected for being immediately downstream of important tributaries. The initial storm sampling plan was to sample several tributaries along the watercourse, and the baseline sampling points would correspond by being located to the outlet points in the brook. The storm sampling plan was modified, but the baseline sampling points were kept, as they also were relatively well spread out along the watercourse. The fifth sampling point was located at the end of the studied reach, also immediately downstream the during storms important tributary of the Station Road.

The baseline sampling was undertaken at five occasions during the spring and summer 2005. It was planned to be done monthly, commencing in April, but for different reasons were not that regular. The second sampling was undertaken in June, with the following three every three weeks thereafter. The sampling was weather-dependent, at least three days of dry weather was arbitrarily chosen to be required, not to let storms interfere with the background water quality. All samplings began at the fifth sampling point, not to risk downstream interference with the results, especially for turbidity and total solids. A thorough presentation of the analytical procedures is given in section 6.3 below.



(After Hess & Tyrrel, 2004)

Figure 6.1 Schematic representation of sampling points along the Sweetbriar Brook, showing the points for baseline, storm and sediment sampling, along with positions of rain gauge and automatic sampler, as well as some main features.

6.2 Storm sampling

The procedures for the storm sampling will be described in this section. The samples were taken at point 5, after the Station Road culvert, showing the overall effects of runoff during the studied reach of the watercourse. The sampling was undertaken during a storm after a long antecedent dry period, a second sampling was planned to be done after a short dry period, but no sufficient rain fell that was possible to sample. The second sampling could therefore not be undertaken. The difference in antecedent dry periods was supposed to show the accumulation of pollutants on the hard surfaces in the catchment. The samples were taken every 4 minutes for one hour, with the exception of thermotolerant coliforms, that were sampled every 8 minutes, due to a lack of sterilised bottles and the lengthy laboratory procedures of analyses. After finishing the sampling at point 5, snapshot samples were taken at points 1-4 for an indication of the water quality at those locations.

An automatic sampler (Montec Epic) had been installed close downstream of the Station Road culvert (see Figure 6.1) to serve as a backup if manual sampling would be difficult to carry out, due to e.g. the time of the day. It held 24 1 litre bottles and was programmed to sample every 4 minutes after manual starting. A rain gauge (Delta, Cambridge) connected to a

data logger (Delta multi-channel data logger, Cambridge) had been set up in a garden close to the brook (see Figure 6.1). The logger time-recorded every 0.2 mm precipitation.

6.3 Analytical procedures for water samples

The analytical methods for the different parameters in the baseline and storm sampling are presented here. The parameters chosen for analysis and measurement were the same for both baseline and storm sampling:

- pH
- temperature
- conductivity
- dissolved oxygen (DO)
- biochemical oxygen demand (BOD)
- turbidity
- total iron (tot-Fe)
- total solids
- oil
- total zinc (tot-Zn)
- total nitrogen (tot-N)
- total phosphorus (tot-P)
- thermotolerant coliform bacteria

Temperature, pH, conductivity and dissolved oxygen were measured with hand instruments (pH-meter WTW pH 320 with thermometer, conductivity meter WTW LF 325 and dissolved oxygen meter WTW Oxi 320) in the field, the other parameters were analysed in the lab. Samples were collected in 4 bottles; a 250 ml sterilised bottle for bacteria analysis, two 500 ml BOD bottles for BOD measurement and a 500 ml plastic bottle for the remaining parameters. The measurements by hand instruments were carried out in the stream, except for points 1 and 2, where water flows out of pipes. The measurements were then taken in the plastic bottles.

Oxygen-related measurements, both DO and BOD, are approximate, but give an indication of the dissolved oxygen (DO) and the biochemically degradable organic matter in the water (BOD), the results must therefore be interpreted with care. The BOD was obtained by measurement of the oxygen concentration in the bottles with a dissolved oxygen meter (Orion model 862) after collection, and then again after five days of incubation in the dark at 20°C. The difference makes up the oxygen consumption (Chapman, 1992). Two replicates were used for each sample.

Turbidity was analysed using a Hach spectrometer (DR/2000) following the manufacturer's instructions for absorptometric method no 8237.

The tot-Fe analyses were also made with the Hach spectrometer (DR/2000), using the Ferrover method with powder pillows according to the manufacturer's instructions.

Total solids were measured by drying 50.00 ml of water at 104°C for 48 hours in pre-weighed beakers, which were then reweighed. The difference in beaker weight showed the total solids (Eaton *et al*, 1995).

For oil analysis a method for fats, oils and grease was used. It seems to be based on the extraction procedure of standard method 2530C for oil and grease (Eaton *et al*, 1995). 150 ml water sample was added to a Duran bottle together with 30 g NaCl, 1 ml 1 M HCl and 25 ml tetrachloroethylene. De-ionised water was used for the blank. The bottles were put on a shaker at 30°C for 30 min. A pipette was used to draw liquid from the solvent layer at the bottom into a cuvette for spectrophotometer measurement (Philips PU9624 FTIR Spectrometer). The cuvette first had to be measured empty, as a blank, before each time being filled. The blank value was then subtracted from the absorbance of the sample, and the remaining value was multiplied with 39.33 to get the concentration of fats, oils and grease in the sample.

The analyses of tot-N, tot-P and tot-Zn were undertaken on filtered samples. For N and P segmented flow analysis (SFA) on an automatic analyser (Burkard) was used. Zn analysis was made with atomic absorption (British Standards, 1995).

The thermotolerant coliform bacteria were analysed using the membrane filtration technique (Drinking water inspectorate, 2002). Filtrations of 1 ml, 10 and 50 ml were used, except for the analyses of the first sampling, where 100 ml instead of 50 was used. Two replicates of each volume were made. The petri dishes were incubated at 44°C for 14-16 hours and the colonies were then counted.

6.4 Sediment sampling

A preliminary and three subsequent sediment samplings were undertaken. The preliminary one was carried out at 4 different sites, shown in Figure 6.1, to give an indication of the characteristics of the sediments. The samples were hand-textured to broadly specify the soil type.

The successive samplings were carried out at points 1, 2 and 4, since point 3 the first time was under too much water from blocking of the weed screen at the Station Road culvert. The bed was also covered in a thick debris layer that remained during the successive samplings. Samples were drawn from three layers at each point; 0-5 cm, 5-10 cm and 10-15 cm. Only one sampling was planned, but the two following were done to verify the results. The only analyses carried out were thermotolerant coliforms and tot-Zn. The number of analyses was kept down, although oil and tot-P were first considered as a part of the analysing scheme. There was no adequate method for oil in sediment, and the phosphorus analysis was rejected due to time shortage.

6.5 Analytical procedures for sediment samples

The methods for sediment analyses are described here. Analyses were done at each of the three layers.

The thermotolerant coliforms were enumerated with the membrane filtration technique after being extracted from the sediments by a method modified after Lang *et al* (2003). 10 g of wet sediment was transferred to a sterilised 125 ml plastic bottle together with 90 ml (first sampling) or 100 ml (second and third sampling) of Ringer's solution and approximately 10 g of glass beads. The bottles were shaken by a Vortex Genie for approximately 4 min before

left to settle. The mixing with the glass beads detached at least some of the bacteria from the sediments, giving the results as the least number of thermotolerant bacteria present in the sediment. For the first set of samples, a dilution series was made where 1 ml was transferred from the 125-ml-bottle to a sterilised bottle with 9 ml of Ringer's solution, and the procedure was repeated from this bottle to another one with 9 ml of Ringer's solution. The membrane filtration was done as with the water samples (Section 6.3), using 1 ml of each dilution, and 1, 5, 10, 15, 20 and 25 ml of the initial solution, differing between each sample in order to draw sufficient volumes from the bottles. The sediment itself should not be sampled, since it blocks the filter paper. This was the reason by experimenting to find the appropriate volumes to be taken from the bottles, not to bring too much sediment to the filter. Incubation and colony counting proceeded as with the water samples. The results were corrected to dry sediment, by measurement of the moisture content. 3.00 g of sediment from each sample was put in pre-weighed tins and dried at 104°C for 48 hours. The tins were reweighed and the difference in weight was the evaporated water.

The total zinc was analysed by atomic absorption after digestion with acids (British Standards, 1998). The sediments were air-dried and grinded with an agate mill prior to analysis.

6.6 Statistical analysis of results

No statistical tests of the results were undertaken, as no replicates had been taken of the samples each sampling time. The use of several variables and different sampling points were prioritised higher than replicate samples for statistical tests. The statistical analysis is only given in the graphical form of diagrams. The consistent trends in the results are hence not statistically assured, which is a drawback of this study.

7 RESULTS AND DISCUSSION

The results from the baseline measurements, storm sampling, and sediment samplings will be presented and discussed here, respectively and in combination.

7.1 Baseline samplings

The 13 variables analysed in the baseline measurements will be displayed and discussed in this section. Each parameter will firstly be discussed separately, followed by a discussion of the general water quality. Figures of all results are given in the sections below, tables with the results are given in Appendix B-D. The figures show the results as bars, which are colour-coded to the sampling points. The results from the first sampling point are not completely comparable; the two first times the water was collected from the pipe itself, but the summer drought then gave too little flow in the pipe to be collected, the last three samples were therefore taken in the pool below the pipe outlet.

7.1.1 pH

The pH values are shown in Figure 7.1, and are within the range 6-8. This is normal for groundwater and corresponds well to a measurement of pH 7.0 in the Woburn Sands aquifer from a borehole near Ampthill (Environment Agency, 1998). The results are similar for all sampling points except 5, which had the lowest values at all samplings, indicating that some acidifying process occurs before or during the passage under the Station Road. It is possible that anaerobic pockets are formed in the standing water before the culvert, where iron is dissolved, causing the pH to drop. This theory was tested by measurements of the pH in the standing water before the culvert over 3 day period, and it was found to be consistently 0.2 pH units lower than in the flowing water in the stream. This is not a very big difference, but still supports the theory. Not much water was standing before the culvert at the time of this short survey either, the pH drop is expected to be larger when more water is standing, making it possible for more anaerobic zones to develop. More water had been standing during most samplings and the difference between points 4 and 5 was then larger than 0.2 pH units. Formation of anaerobic environments can cause metals to dissolve, making them more bioavailable and hence threatening the health of the aquatic organisms (Larm, 1994). Another theory for the lower pH at point 5 is a groundwater spring, with more acid water emerging there. This theory does however seem weaker, since the pattern of the pH at point 5 follows the one of points 3 and 4, and not 1 and 2, which are thought to be derived principally from groundwater. The quality of groundwater can nevertheless change spatially, and the higher iron concentrations present at point 5 (see Section 7.1.8) could support the groundwater theory. The lower pH before the culvert however strongly justifies the former theory. It is unfortunate that it could not be tested during conditions with higher water backup.

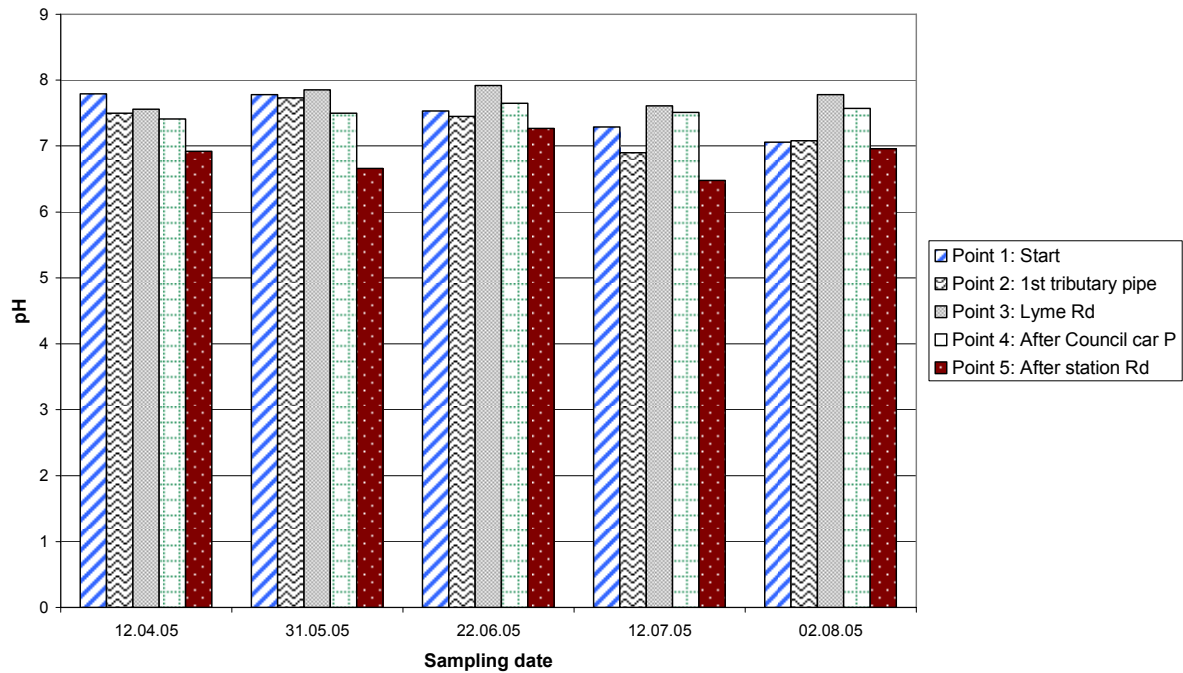


Figure 7.1 Baseline pH at the 5 sampling points and sampling times.

7.1.2 Temperature

The temperature data is given in Figure 7.2, and shows the lowest values at the starting sampling point, generally increasing downstream. The water at the second sampling point is warmer than expected, since groundwater normally is relatively cold and stable in temperature. The downstream differences can be due to different weather at the different sampling occasions; time of day and sunshine or not give visible changes in such shallow water.

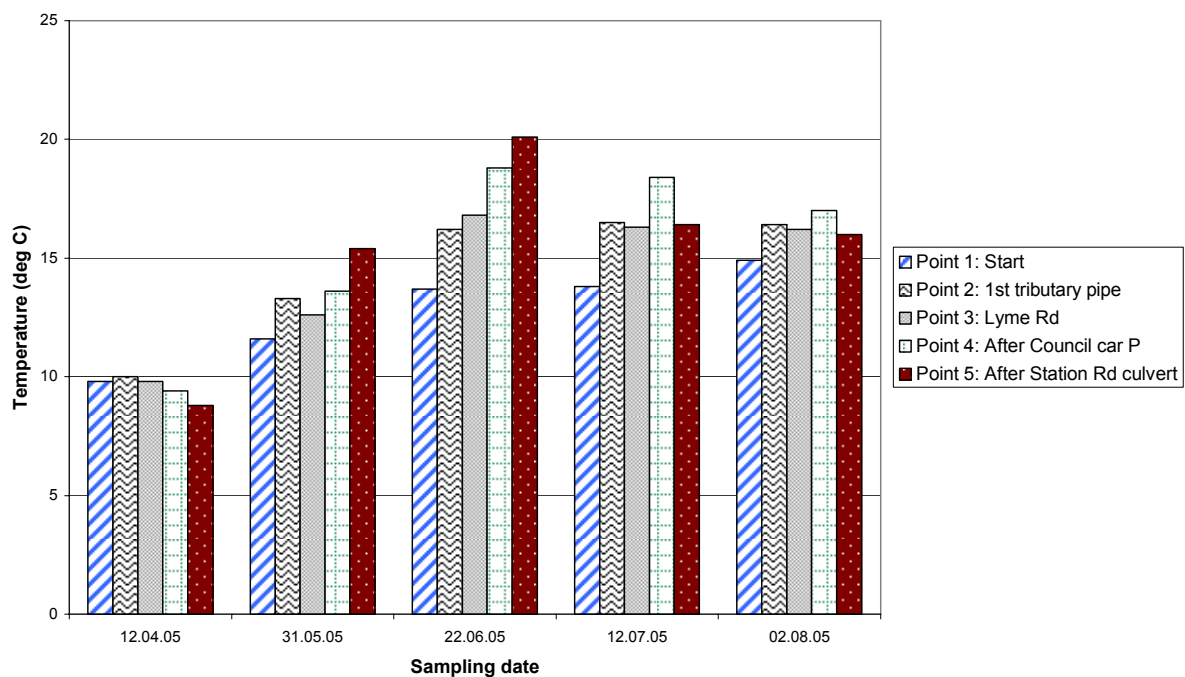


Figure 7.2 Baseline temperature at the 5 sampling points and sampling times.

7.1.3 Conductivity

The results, shown in Figure 7.3, are relatively consistent for each sampling date. Point 5 varies some at samplings 3 and 4. The values for samplings 1 and 2 are higher than the following ones, and are also more consistent through the sampling points. This might be due to the higher discharge during spring than summer, also bringing more salts, creating an electrical current. There is a consistency in pattern with tot-P and tot-N for sampling point 2 (see Section 7.1.10), but not for parameters such as turbidity or total solids.

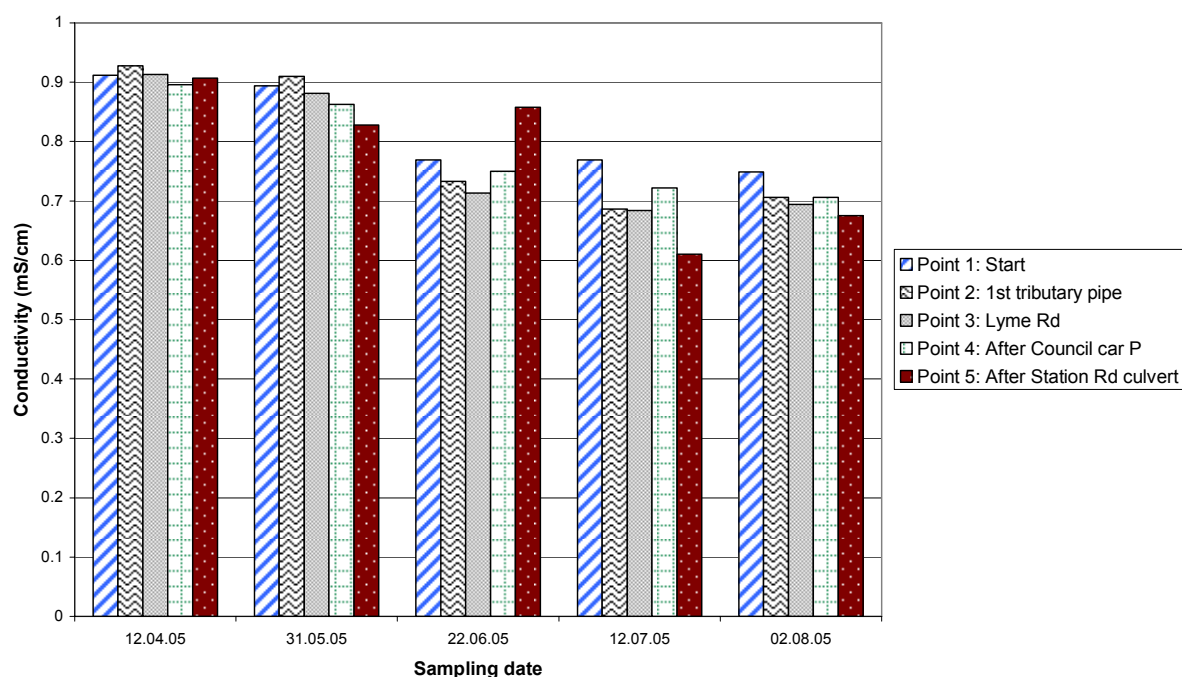
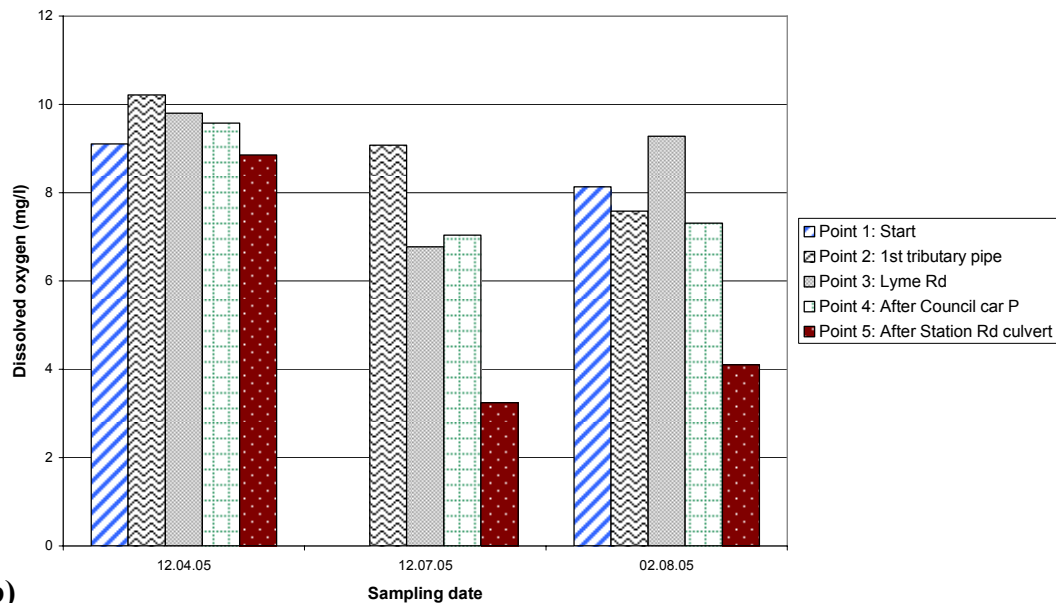


Figure 7.3 Baseline conductivity at the 5 sampling points and sampling times.

7.1.4 Dissolved oxygen (DO)

There is no complete record for DO readings, since the DO-meter did not work satisfactorily at all times. The obtained results are shown in Figure 7.4 a and b, where the first figure shows the values as a concentration and the second as percentage of saturation. In that measuring mode, a function adjusts for temperature, as higher temperatures cause lower dissolved oxygen concentrations. DO-measurements are not very reliable, and the interpretations should therefore be made with care. The clearly different pattern is the consistently lower values at point 5, which likely are due to oxygen consumption in the standing water before the Station Road culvert. These values are very low; DO concentrations below 5.0 mg/l put stress on the aquatic life (Kentucky water watch, 2005), but the results in general are normal.

a)



b)

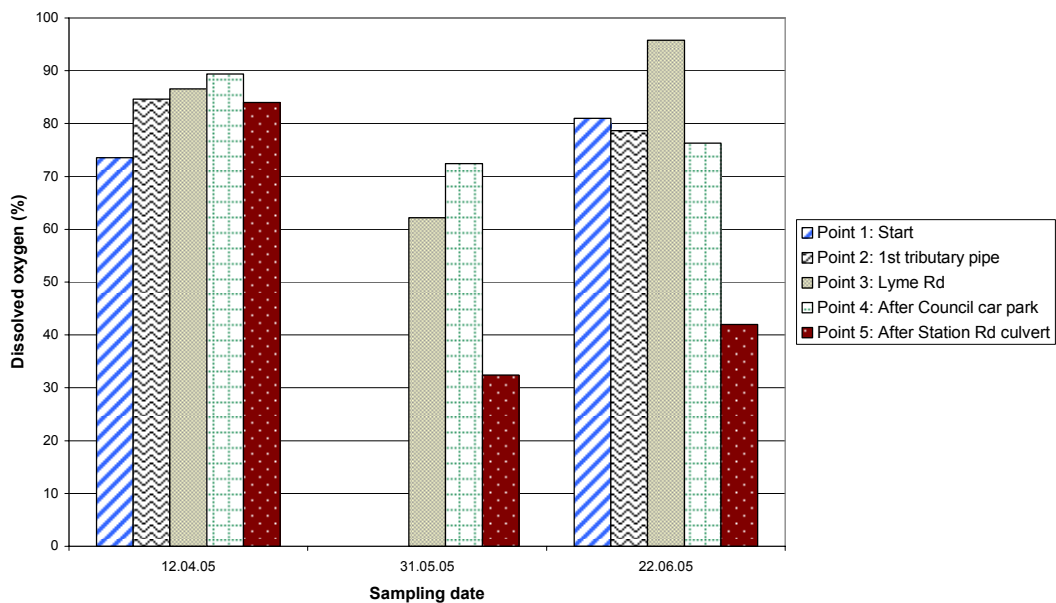


Figure 7.4 Dissolved oxygen at the 5 sampling points for samplings 1, 4 and 5, a) as mg/l, with the measurement for point 1 missing for sampling 4, b) as percentage.

7.1.5 Biochemical oxygen demand (BOD)

BOD values were obtained for the 4 first samplings, as an equipment failure made the readings of the last sampling impossible. The results are shown in Figure 7.5. The BOD at point 1 is rising after the second sampling, likely due to that the water was taken from the pool instead of the pipe. The reason for the much higher value of 22.06.05 is however uncertain. Higher values are also observed at points 4 and 5 that day, together with a pattern of higher values downstream in turbidity, coliforms and also slightly in temperature. The BOD levels are generally low, mostly below 2 mg/l. Unpolluted waters are characterised by values below 5 mg/l (Exploring the environment, 2005), and the results hence comply with the expectations of the water quality of the brook. As the BOD measurement is a measure of the dissolved oxygen concentration, it is associated with uncertainties and should be interpreted carefully.

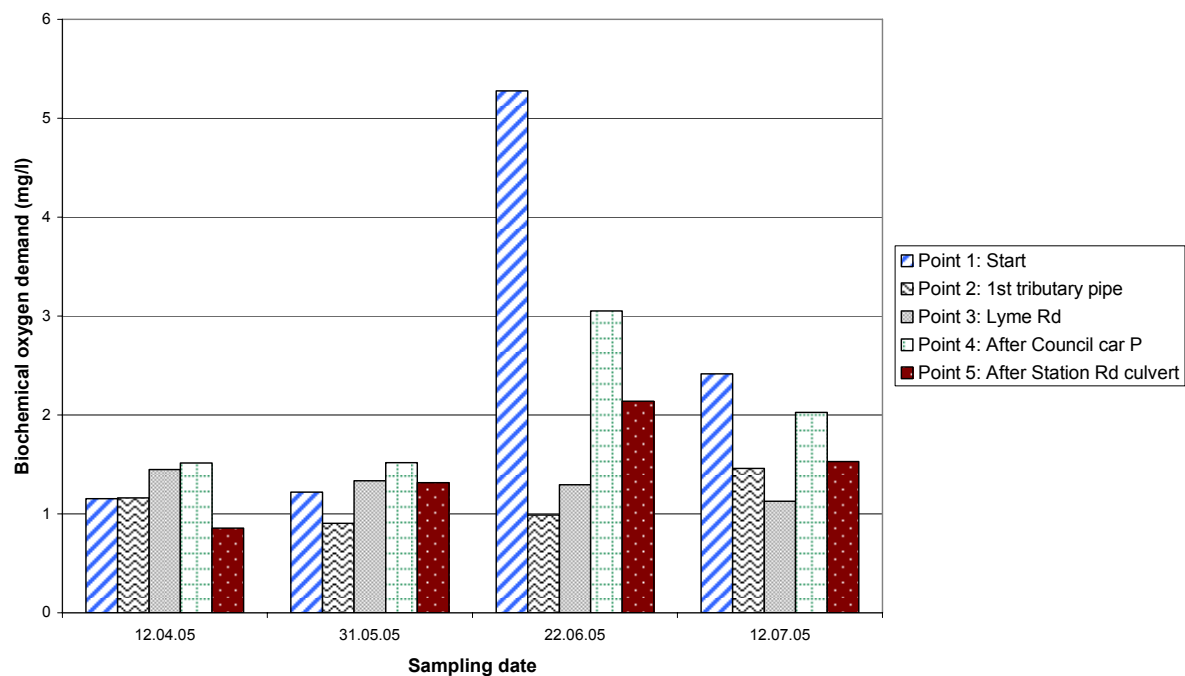


Figure 7.5 Baseline biochemical oxygen demand (BOD) at the 5 sampling points for the first 4 sampling times.

7.1.6 Turbidity

The results are given in Figure 7.6, showing a pattern with the highest values on 22.06.05 for all sampling points. This is especially clear for the first one, where the high value of 63 was removed from the diagram, enabling to see the other results more clearly. The 3 last samples at the start pipe were taken in the pool below the pipe outlet, giving the difference compared to the first two samplings, even though the high value of 63 cannot be explained by this. There is a consistent trend with high values for that day. The general patterns of turbidity are also seen in the total solids results. The values are generally low, as expected, and the samples were often clear to the eye, although in some cases had a yellow colour.

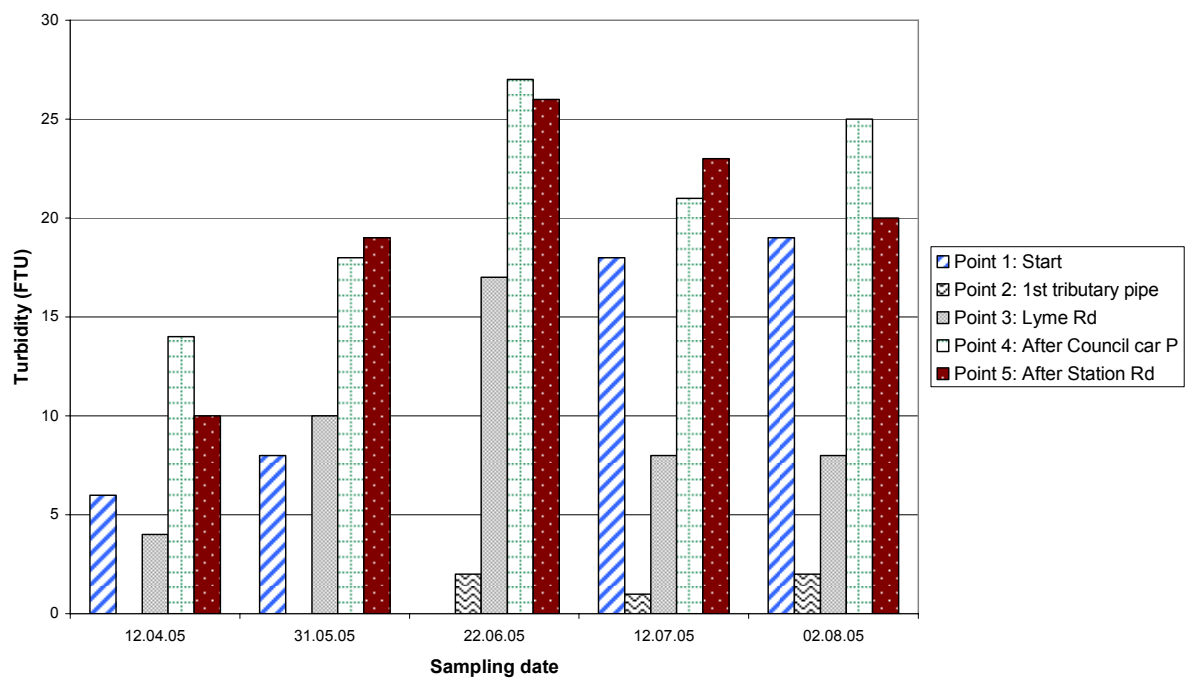


Figure 7.6 Baseline turbidity at the at the 5 sampling points and sampling times, with the point 1 value of 63 removed for sampling 3, 22.06.05.

7.1.7 Total solids

The results, shown in Figure 7.7, are generally consistent over both time and sampling points. The largest exception is point 1 at sampling 3, where high values also were present in turbidity and BOD. Only this day seems to be affected by sampling in the pool instead of the pipe, however, as the values from samplings 4 and 5 for point 1 are not increased, compared to the first two samplings. A slight increase at all sampling points on the third sampling however indicates a higher particle load in the water, also visible in the turbidity.

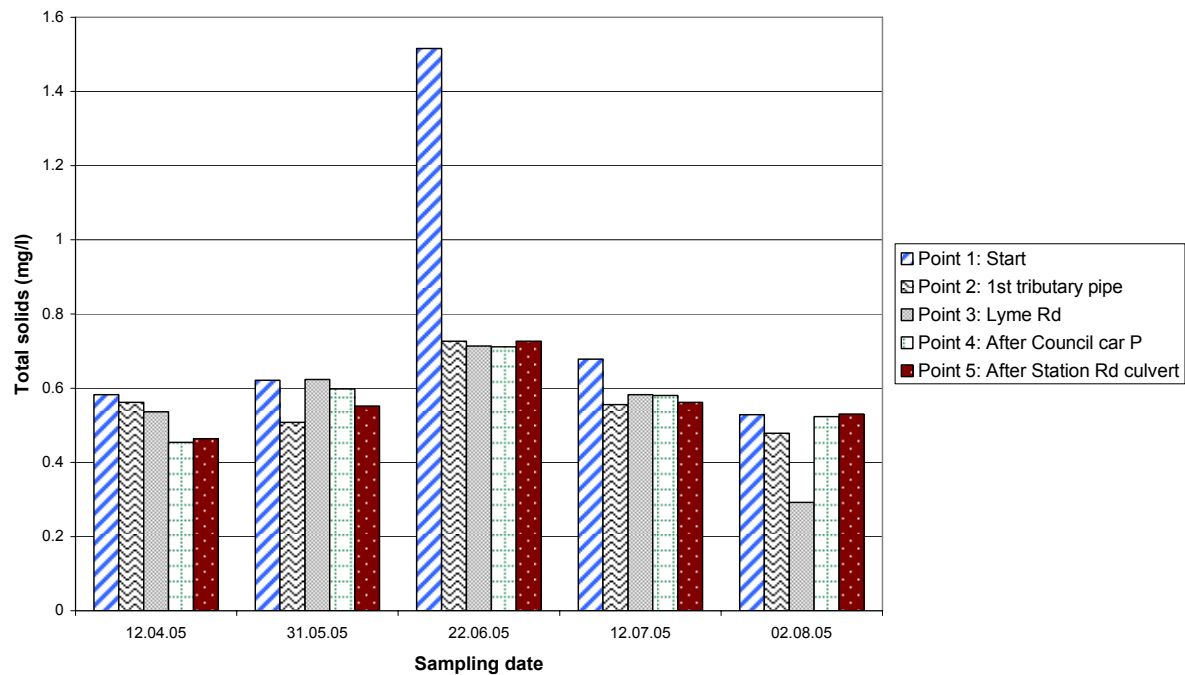


Figure 7.7 Baseline total solids at the 5 sampling points and sampling times.

7.1.8 Total iron (tot-Fe)

There is a relatively clear pattern in all the sampling points over time, see Figure 7.8. Most points show rising Fe-concentrations with time. The highest values are generally seen at points 1 and 5. The much lower concentrations at point 2 show the differences present in groundwater quality even at short distances. The Woburn Sands aquifer is known to have elevated iron concentrations, a study at three boreholes near Cambridge (Environment Agency, 1998) gave values of 0.4-2.0 mg/l, and an old survey of water from a borehole near Ampthill (British Geological Survey, 1994) showed 2.3 mg/l. Compared to these findings, the concentrations at point 1 are well within the expected range of groundwater from the Woburn Sands.

The sharp rise in concentration in sampling 3 at point 1 is probably due to sampling in the pool instead of the pipe. At point 5 there could be a groundwater spring, causing the elevated levels, but the theory presented in Section 7.1.1 is more likely. Anaerobic zones formed in standing water prior to the Station Road could culvert cause iron to dissolve into the ferrous ion Fe^{2+} , and increase the concentration in the water. The mobile Fe^{2+} is then also more likely to be sampled, than when being in particulate form (Bartram & Ballance, 1996). Iron precipitation is seen after the culvert, where much of the bed is covered in orange ferric oxide, which likely originates from pH rise and aeration when the water passes the culvert, causing the iron to oxidise into the Fe^{3+} form. There might have been no standing water before the culvert on the first sampling, and therefore the concentration remained from point 4 to 5.

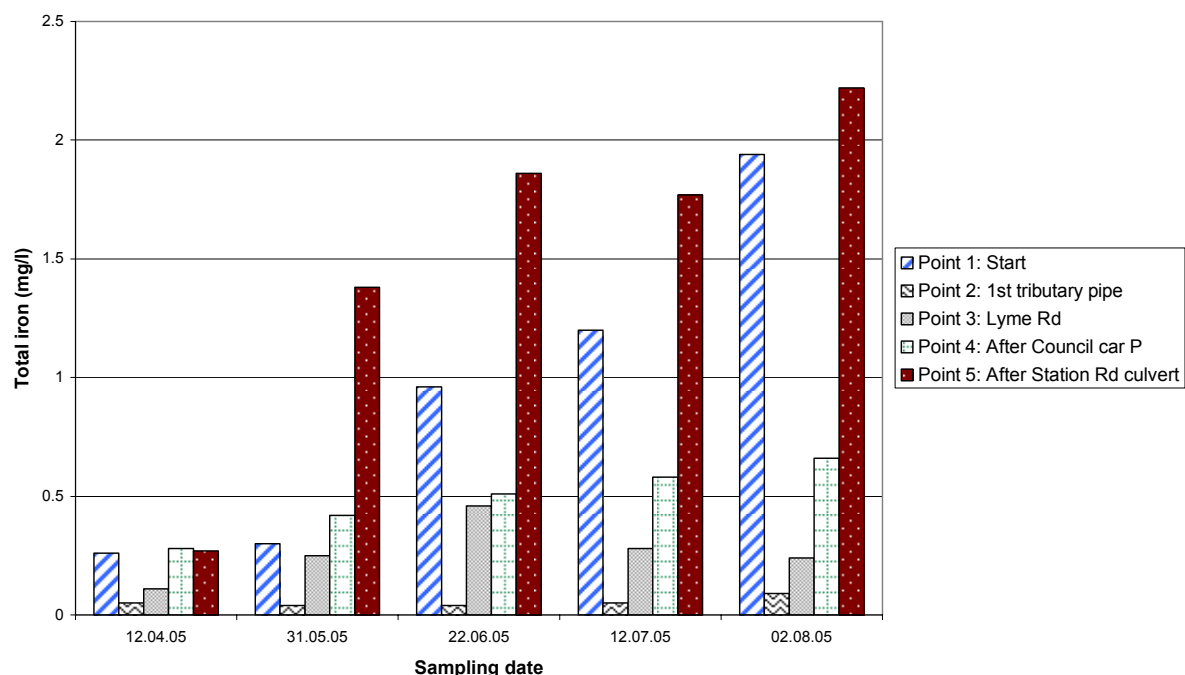


Figure 7.8 Baseline total iron at the 5 sampling points and sampling times.

7.1.9 Total nitrogen (tot-N)

The values for tot-N, shown in Figure 7.9, are within 3-8 mg/l. The results differ in pattern between sampling point 1 and the others. While the concentrations increase in the summer at point 1, they decrease downstream at the other sampling points. This seasonal pattern might indicate some relationship with N uptake by plants, but without a clear understanding of the origin of the water this is purely speculative. The nitrogen is likely to be in the mobile nitrate form, originating from fertilisers spread to arable land in the Woburn Sands area. Presuming all nitrogen were in the nitrate form, the values are moderately low – high in the General Quality Assessment classification (3-8 mg/l NO₃-N is roughly equivalent to 13-36 mg/l NO₃, that are within the given classes in the classification) (Defra, 2002). Since Ampthill is located in an agricultural area in a part of the country threatened by high nitrate levels in the waters, these values were expected. Another parallel can however be drawn to the discharge requirement concentration of the Urban Wastewater Treatment Directive (91/271/EEC), which is 15 mg tot-N/l to sensitive waters (Europa, 2005). Compared to this consent are the concentrations not more than moderate.

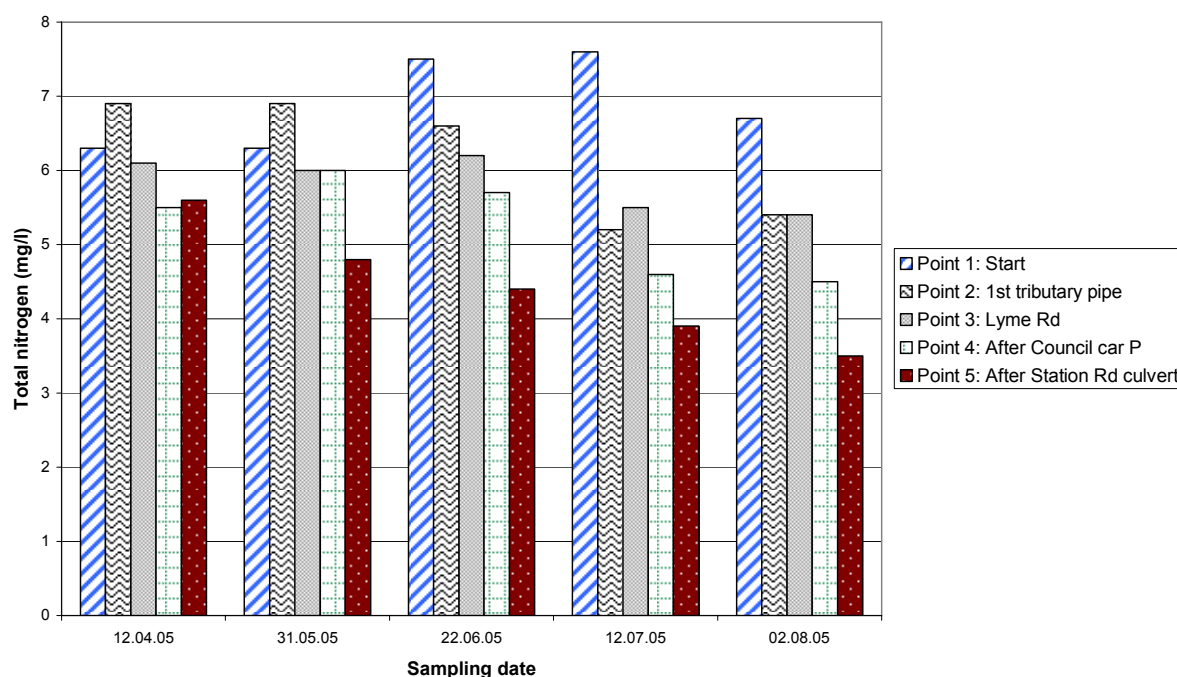


Figure 7.9 Baseline total nitrogen at the 5 sampling points and sampling times.

7.1.10 Total phosphorus (tot-P)

The tot-P data, shown in Figure 7.10, generally demonstrates more variation than the tot-N. There is phosphorus in pipe at point 2, but not in the headwall pipe. The concentrations are declining downstream. Phosphorus is normally expected to be particle-bound, but the analyses were done on filtered samples, therefore only soluble P is shown. The source is however unknown. The pattern would suggest fertiliser from the Alameda playing field, but it is highly unlikely that any is spread. The observed levels of phosphorus are generally below 0.2 mg/l, with a few much higher exceptions. These values are very high compared to different water quality guidelines of e.g. 0.01-0.1 mg/l (National pollutant inventory, 2005) for streams and rivers. Surface waters in this part of UK are at risk from high P levels (Defra, 2002), and these results should therefore have been expected. It is unknown how high the values actually are, since particulate forms were not analysed.

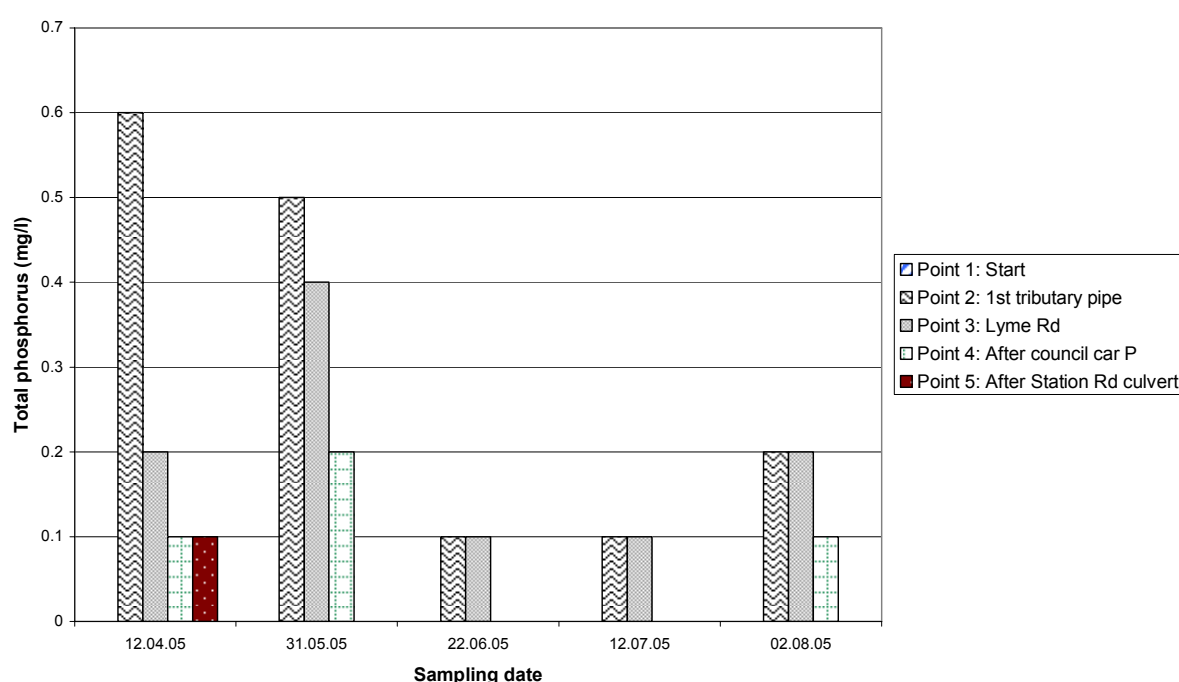


Figure 7.10 Baseline total phosphorus at the 5 sampling points and sampling times.

7.1.11 Total zinc (tot-Zn)

The results from the zinc analyses, given in Figure 7.11, show no consistency in space or time. Higher values were expected at points 3-5, where areas subject to more traffic are close-by, and more sources of zinc were expected to be present. The fact that the samples were filtered prior to analysis have excluded the particle-bound form, the original pattern might therefore have been different. Trace amounts of metals from weathering of rocks and soil are always present in freshwaters, and might be a source particularly for points 1 and 2. All results are however very low; the water quality standard for drinking water allows 5.0 mg/l (The water service, 2002).

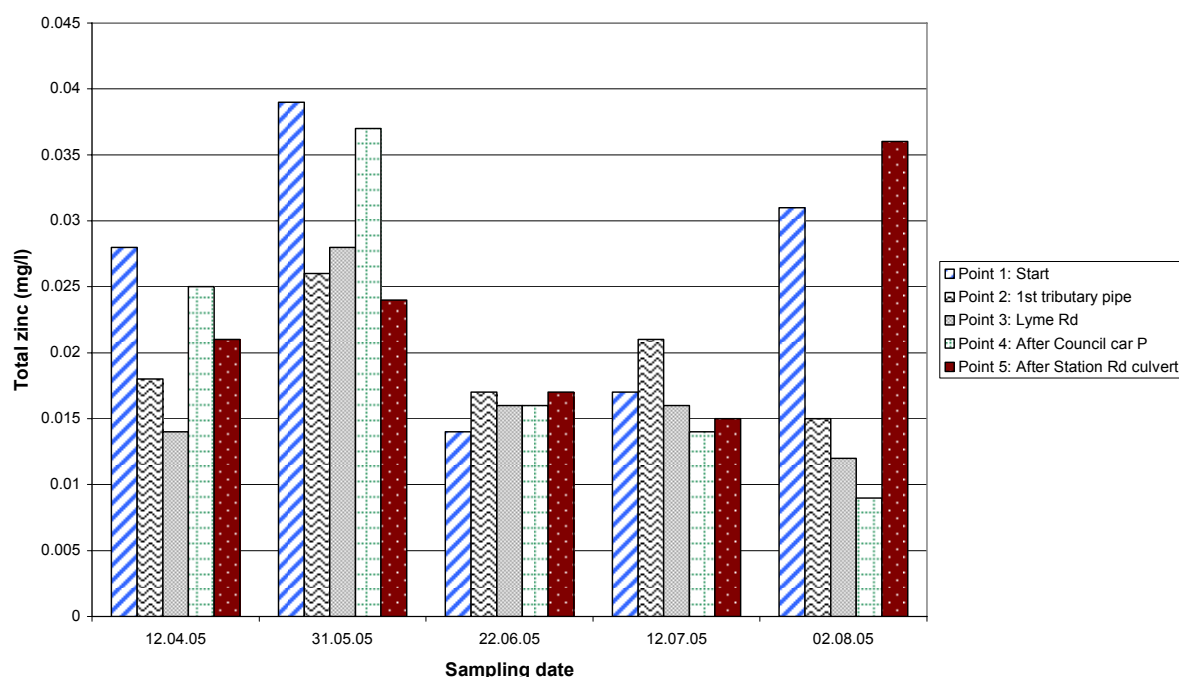


Figure 7.11 Baseline total zinc at the 5 sampling points and sampling times.

7.1.12 Oil

The method analysed fats, oils and grease (FOG) present in the water, and the results are shown in Figure 7.12. There are differences in both time and space, and it is possible that they to some extent are due to measurement errors. The high concentration at point 2 on 22.06.05 might be due to machine leakage. Shortly before the third sampling, gravel had been spread on the footpath at the outlet of pipe 2, as water had been emerging there, muddying the footpath. This value is very high, but sensible, if originating from a maintenance vehicle. Traffic areas have oil concentrations from 2.0-400 mg/l, so in this context the levels in the brook are low. However, in general runoff, the concentrations vary between 0.4-3.3 mg/l (Larm, 1994). Still, the levels sometimes seem high for this mainly residential catchment, although access roads and car parks are found. The substances causing increasing levels do however not have to come from vehicles and related activities, but can also be waxes from plants or food (Butler & Davies, 2000), making it more difficult to define the source. The concentrations at point 5 are always low, this may be due to that the FOG gets stuck in the debris partly or totally blocking the Station Road culvert.

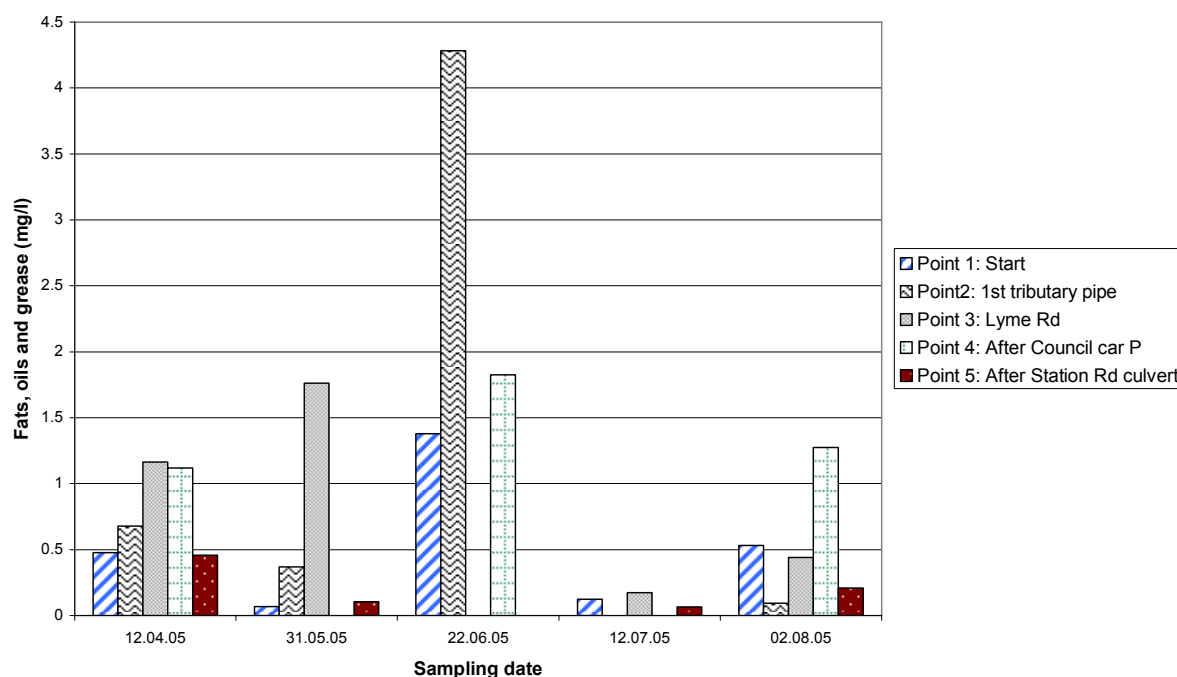


Figure 7.12 Baseline fats, oils and grease at the 5 sampling points and sampling times. The hidden value at point 5 on 12.04.05 reads 0.2 mg/l.

7.1.13 Thermotolerant coliform bacteria

The number of bacteria present in the water is given in Figure 7.13 a and b, with the highest values removed from Figure a, showing the lower values more clearly. The data contain both high and low values, with great variations in time and space. The only consistency is found in the second sampling point, where the results always were 0. The bacteria in the headwall pipe are probably due to rodents and their faeces. Different animal sources are of course likely for any of the other points. The dramatically high concentrations found in the third and fourth samplings might be due to such an input, even though the levels seem very high, but high numbers of coliforms can be present in small amounts of faeces. A comparison of the bacteria levels was made with the Bathing Water Directive (EC 78/160/EEC), where the compliance level is 2000 faecal coliforms/100 ml in 95% of the samples (Environment Agency, 2005). The brook had higher, and occasionally dramatically higher, levels of faecal, or thermotolerant, coliforms, and did not comply with bathing water standards.

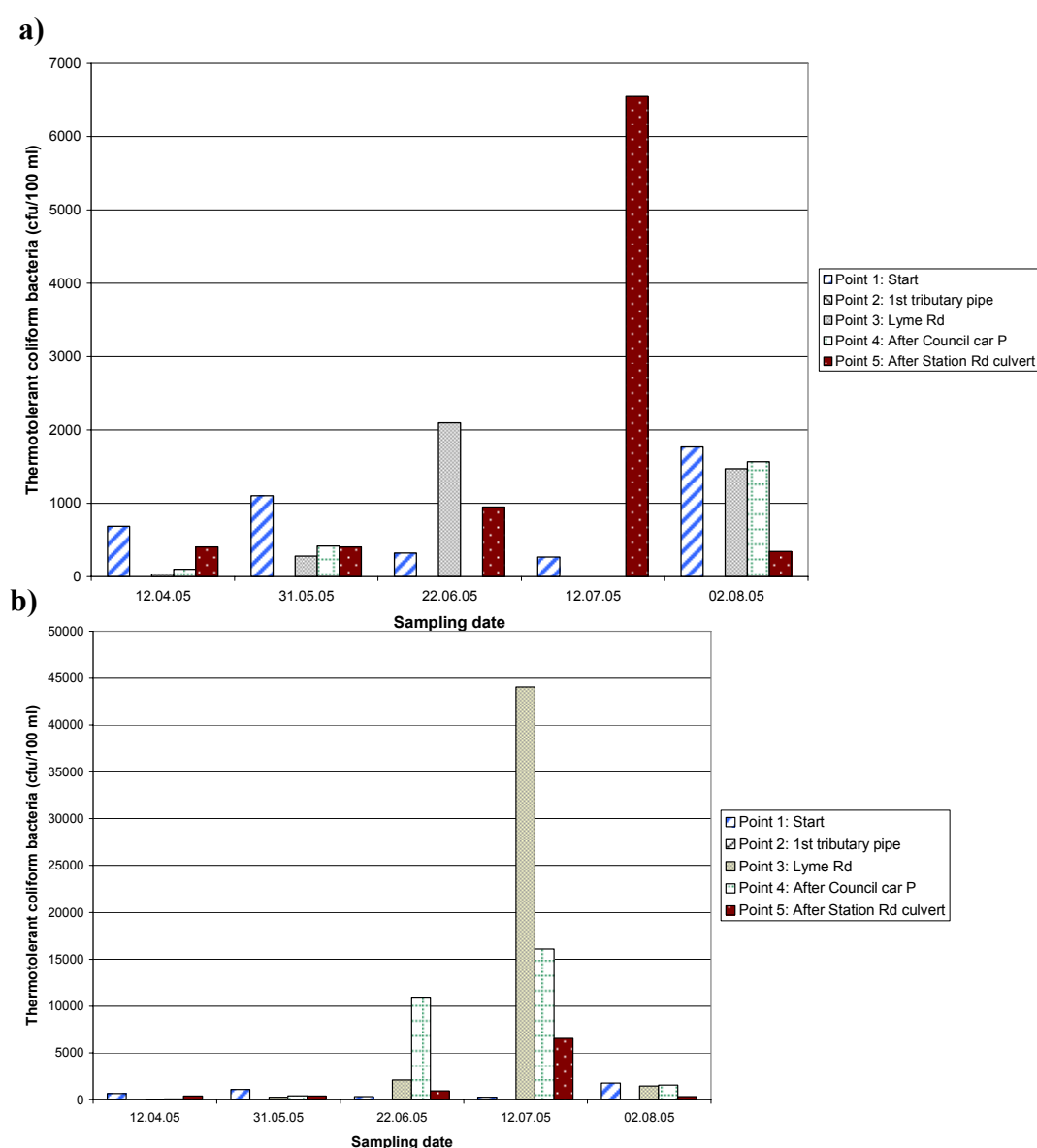


Figure 7.13 Baseline thermotolerant coliform bacteria at the 5 sampling points and sampling times, with the 3 highest values removed in a), enabling the lower results to be shown in a more clear way. In b) all bars are presented. The unit cfu stands for colony forming units.

7.1.14 Overview of the water quality of the Sweetbriar Brook in low flow conditions

The water quality was generally good, with a few exceptions. The numbers of thermotolerant coliform bacteria were occasionally very high, posing a potential health risk to children playing in the water. The nutrient levels were also high, particularly phosphorus, that greatly exceeded guidelines at some sampling points.

Elevated iron levels were seen at points 1 and 5, in the first case due to naturally higher concentrations in the Woburn Sands aquifer. At point 5 the values were probably caused by anaerobic zones formed before the Station Road culvert, causing iron to dissolve. Other metals can also dissolve under these conditions.

The oil concentrations were a little higher than expected in this mostly residential catchment, but the sources are difficult to define. The water was however clear and generally well aerated, with the exception of the standing water before the Station Road culvert. At normal, dry conditions, the water did not seem to be affected by runoff and associated pollutants. This conclusion can however not be drawn with any certainty from these chemical data only. Biological sampling and longer monitoring with replicates allowing statistical analysis is needed to verify these results.

7.2 Storm sampling

On 24th June, following one and a half week of dry weather, a storm came, making it possible to sample with dry antecedent conditions. Rainfall times and intensity were recorded some 100 m from the brook (see location in Figure 6.1), and are shown in Figure 7.14. The rainfall commenced at noon, and the sampling at point 5 about one hour later, lasting for one hour. Thereafter the sampling points 1-4, in reverse order, were sampled to provide a snapshot of the water quality at each location during the storm. It was not continuously raining during the samplings, the snapshot samplings were undertaken in a dry spell before the rain commenced again with its highest intensity. The discharge seemed normal during these additional samplings, after being high-levelled, fast-flowing and turbid during the sampling at point 5.

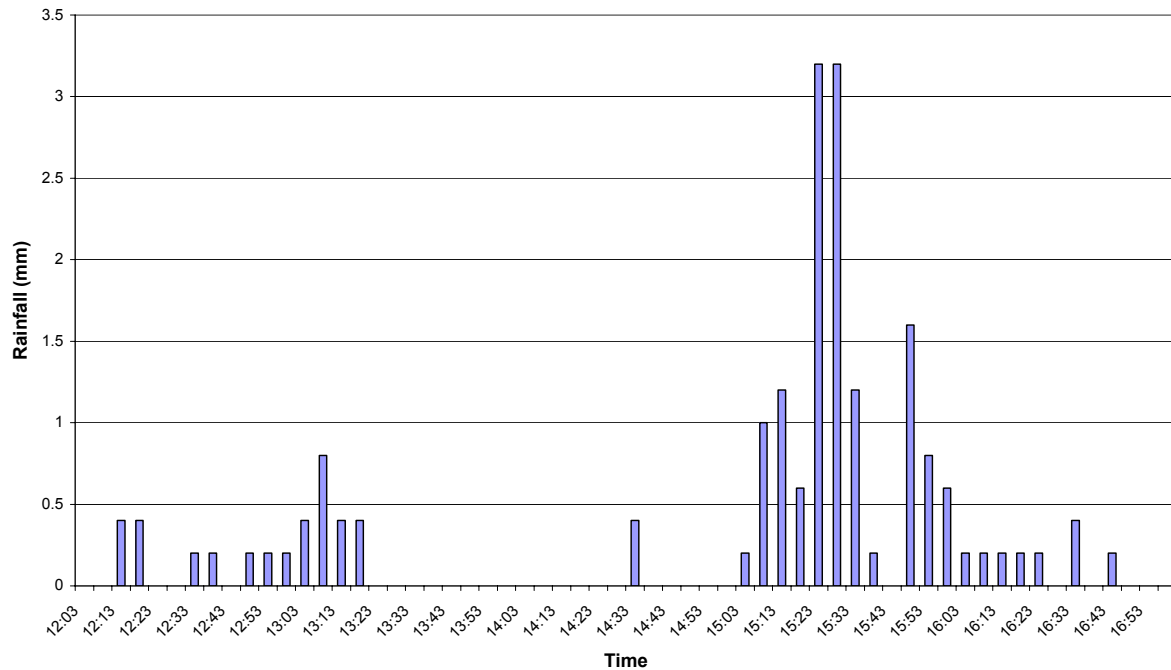


Figure 7.14 Recorded rainfall and intensity at the day of the storm sampling, 24.06.05.

Data were not obtained successfully from all samplings, due to stressful moments (causing e.g. fewer data for sampling no 5), and downpouring rain when finishing sampling point 1. Commencing the sampling one hour after the rain began meant the expected first flush was not caught in the sampling. This fact caused difficulties in the characterisation of the stormwater quality, since much of the pollutants occur in the first flush. In some results the decreasing tail can be seen, before the rise of a new peak, in what is believed to be the first flush from another part of the catchment. It seems the catchment can be divided into subcatchments, each having different response times to rainfall, and therefore also different timings of the first flush. This was observed by Hess and Tyrrel (2005, pers com) during 2004, when different tributary pipes discharged heavily at different timings during rainfall. A similar observation was also made during the storm sampling at point 1, where the flow suddenly went from nearly nothing to very high and turbid. The pattern with more than one flush is obvious for e.g. turbidity, see Figure 7.15.

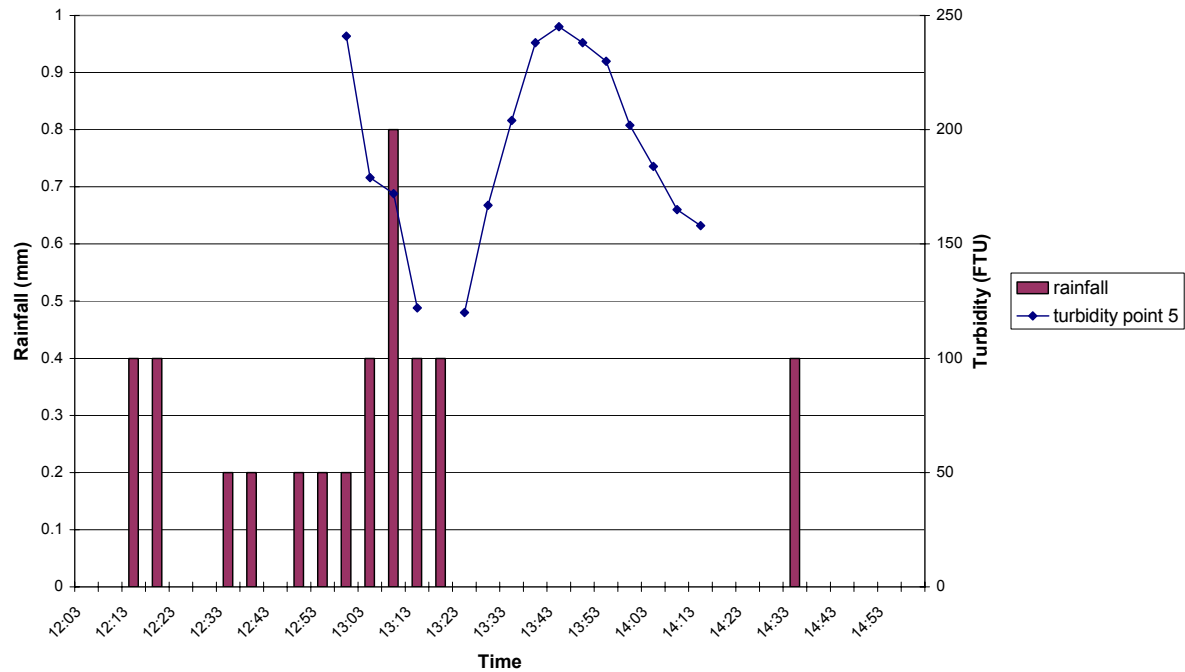


Figure 7.15 Rainfall and turbidity during storm, with the pattern of decrease followed by a second flush.

The individual variable results will be presented and discussed below, followed by a general discussion. In the figures the results from the interval sampling at point 5 are shown in points and lines, while the sampling results from points 1-4 are given in individual points, coloured by sampling point.

7.2.1 pH

The results are shown in Figure 7.16, appearing very even through the sampled hour, as well as at points 1-4. The values also correspond well to the baseline results. No changes in acidity during the storm were thus occurring.

7.2.2 Temperature

The results, presented in Figure 7.16, show a decline at first, followed by a small rise in what is believed to be the runoff from a different subcatchment. Another theory in this case is that the delay in temperature rise compared to other variables (see e.g. turbidity and total solids in Figure 7.18) indicates that some time of turbulence in the channel is needed to increase the temperature. The temperature at points 4-2 (no measurement was made at point 1) were decreasing, probably due to the return to normal conditions with normal flows.

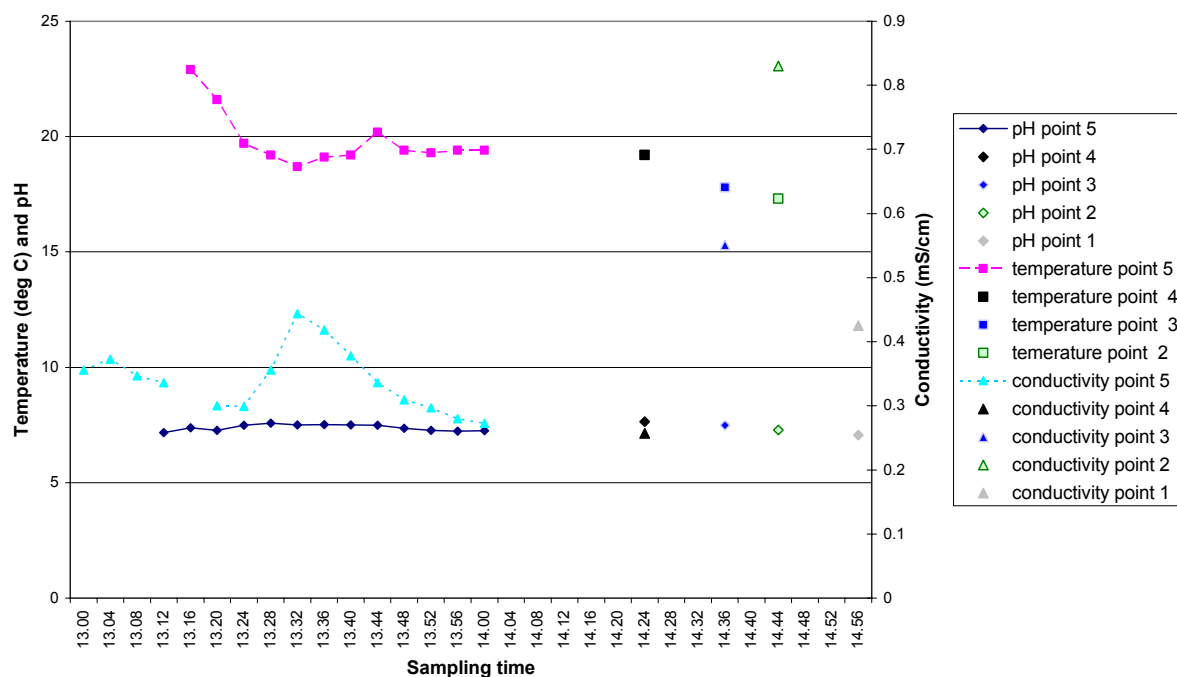


Figure 7.16 pH, temperature and conductivity during storm, shown as lines for point 5, and as individual points for points 1-4.

7.2.3 Conductivity

Figure 7.16 shows the decreasing tail of what is believed to be the first flush from one subcatchment, followed by a peak from another one. The values are however lower than during baseline conditions, possibly due to the lower conductivity of rainwater (Waterwatch Australia, 2002). The observed peaks are likely consisting of some mineral salts and charged soil particles that were washed into the watercourse. This is also supported by the data of total solids and turbidity (Figure 7.18). The rising series for points 4-2, with a low point 1 are also seen in total solids, see Section 7.2.6.

7.2.4 Dissolved oxygen (DO)

DO shows a different pattern than most parameters, see Figure 7.17. The curve would be expected to dip at the peaks of other parameters, caused by low oxygen concentrations in the polluted water, but it seems turbulence kept it aerated. BOD would likely have showed a corresponding dip, but mistakes in the analyses made the results fail. The points 4-2 (1 was not measured) show lower values than at 5, there is no explanation for this pattern. The values are even lower than in the baseline for this point. The baseline DO concentrations at point 5 were on the other hand in 2 out of 3 cases lower than the storm concentrations there, showing either a poor aeration during normal conditions, or very good aeration during the storm. According to the baseline DO discussion, the latter is more likely.

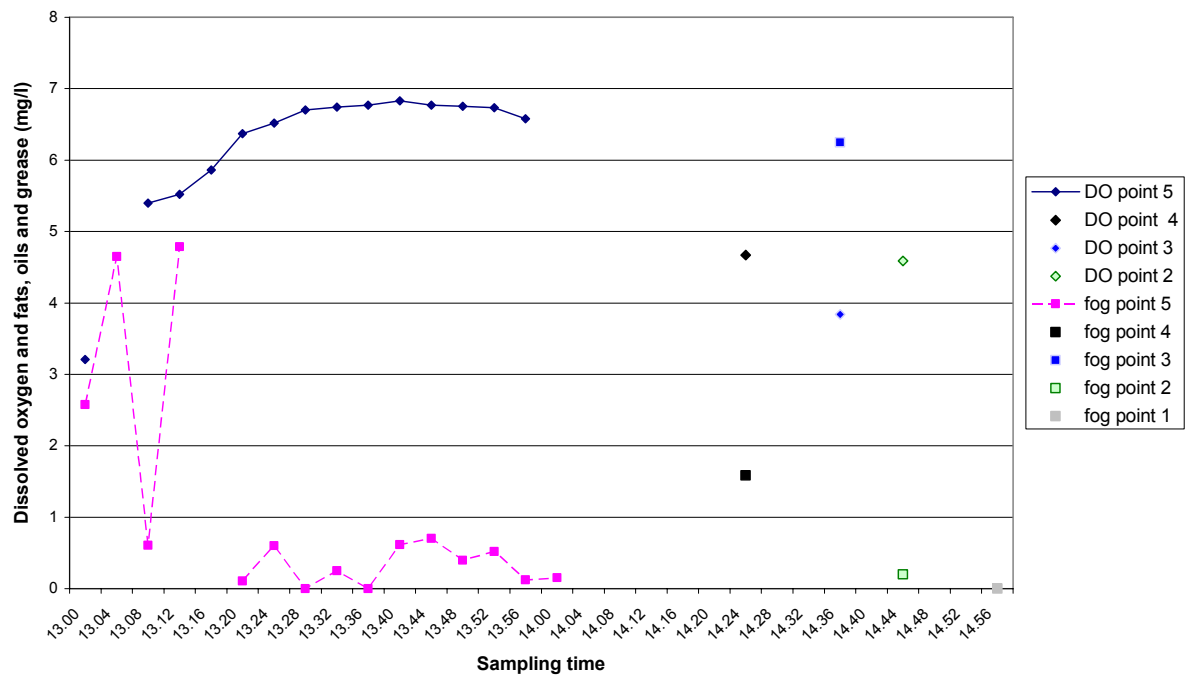


Figure 7.17 Dissolved oxygen (DO) and oils, fats and grease (FOG) during storm, shown as lines for point 5, and as individual points for points 1-4.

7.2.5 Oil

The concentrations of fats, oils and grease, shown in Figure 7.17 vary at the beginning, before stabilising at a lower level. This indicates origin from subcatchments differing in oil pollution, e.g. a car park in the first one, and an area of low traffic in the second. Points 4 and 3 show higher, or much higher concentrations, respectively, while points 2 and 1 are very low. The reason for the high level at point 3 is unknown. The possibility of measurement errors always exists. The low concentrations at point 1 and 2 are sensible, since there are no traffic-related sources that could give high values at those points. The stable lower values at point 5 and the levels at points 4, 2 and 1 are all within the range of the baseline concentrations.

7.2.6 Turbidity & total solids

The results for turbidity and total solids are given in Figure 7.18, and they follow each other closely during the flush at point 5. Turbidity shows a dramatic decrease in the first samples, in what seems to be the tail of a first flush from one subcatchment. That pattern is not apparent for the total solids. As seen in Figure 7.15, the turbidity, and hence also the total solids, respond to the rain in a clear way. Noticeable is however the scales, where turbidity is very high, up to 10 times higher than the baseline values. This was also visible when looking at the black water, but total solids are mostly in the same magnitude as in the baseline. These results are anomalous, also since the conductivity values are low (see Section 7.2.3). The pollutants can therefore not be dissolved salts that would give readings for turbidity and conductivity, but not for total solids.

The pattern for total solids at points 1-4 are the opposite of the pattern for turbidity and conductivity, indicating that the proportions between dissolved salts and solid matter differ at each point. A clear example is seen at point 2, where the turbidity was 0, indicating that only solid particles, and no salts were in that water.

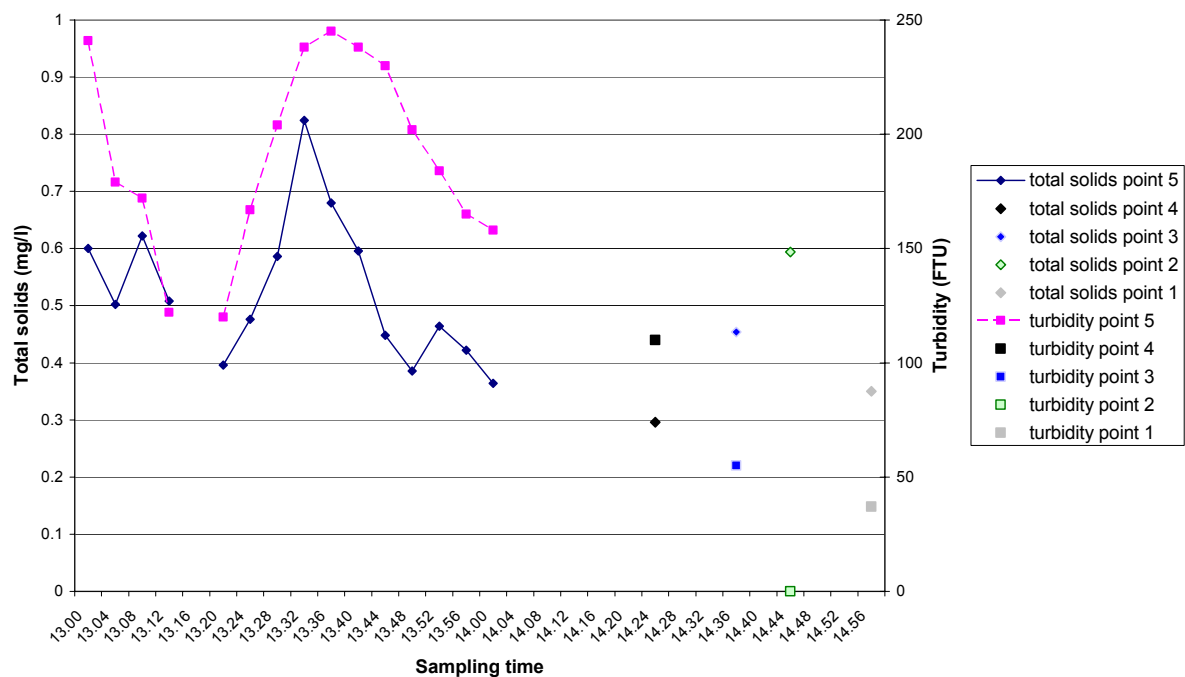


Figure 7.18 Total solids and turbidity during storm, shown as lines for point 5, and as individual points for points 1-4.

7.2.7 Total iron (tot-Fe)

The iron follows the pattern of many others, with a tail from one flush and the peak of a next, see Figure 7.19. The levels are more than three times higher than those of points 1 and 5 in the baseline where iron already is higher, but the sources are impossible to trace, since iron is very common both in the soil and in different metal structures. The concentration is declining along points 4-2, and is back to normal at point 1. There it is the same as for the first two baseline samplings that were taken from the pipe, just as this one was.

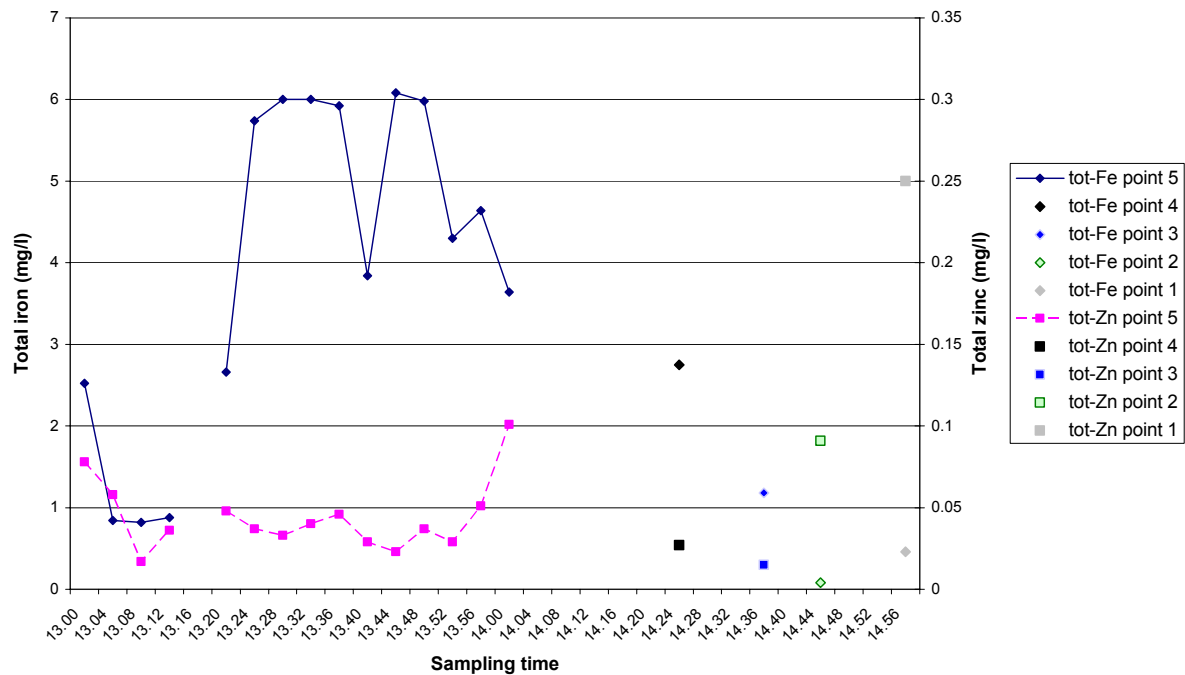


Figure 7.19 Total iron and total zinc during storm, shown as lines for point 5, and as individual points for points 1-4.

7.2.8 Total zinc (tot-Zn)

The pattern with runoff peaks from different subcatchments is also visible for zinc, see Figure 7.19. Here does however the second visible flush come later compared to other variables, possibly originating from a flush from a different subcatchment than the others. The concentrations at point 5 are generally lower than the levels in the groundwater at points 1 and 2, where the values were expected lower, since fewer sources are possible. Zinc is a traffic and roadside-related pollutant, which was expected to show. Only a part of the runoff was on the other hand sampled; higher concentrations can have passed before or after the sampling hour. Due to the available method was the analysis also undertaken on filtered samples, any particulate form of zinc was therefore excluded, which can have an impact on the results. The particulate phase of metals is the most common one in stormwater, according to Butler and Davies (2000). The shown results are well below the normal stormwater from different environments, possibly partly due to this fact. Stormwater in general contains 0.3 mg/l, residential areas have 0.2 mg/l (Larm, 1994).

7.2.9 Total nitrogen (tot-N)

The total nitrogen concentrations, given in Figure 7.20, vary in only a small span, without patterns of rises and falls seen with some of the other parameters. The values of all sampling points are within the results of the baseline, which indicates no new sources of nitrogen during the storm.

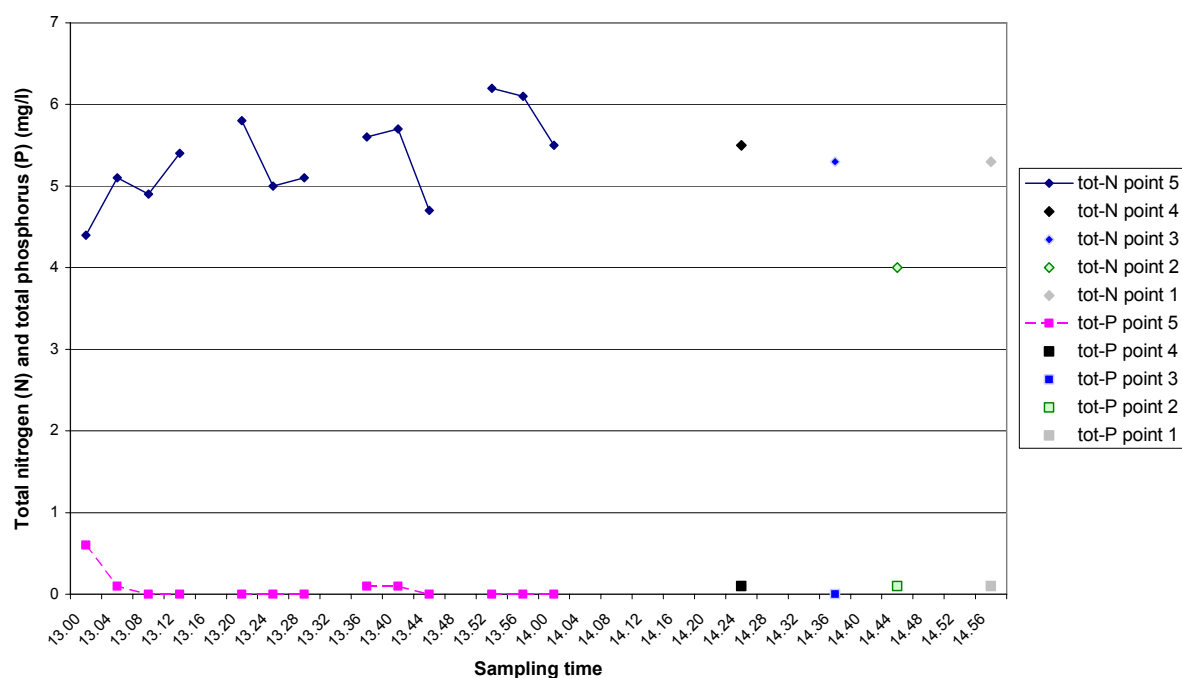


Figure 7.20 Total nitrogen and total phosphorus during storm, shown as lines for point 5, and as individual points for points 1-4.

7.2.10 Total phosphorus (tot-P)

Only low, mostly 0, concentrations of total phosphorus was found, see Figure 7.20. The samples were however filtered, excluding particle-bound P from the analysis. This could be a reason for the low values, since it is known that soil always contain particle-bound phosphates, and obvious soil erosion around point 2 was occurring during the sampling. Even though the amounts of particulate phosphorus in the samples are unknown, very little dissolved phosphorus was carried in the water. The values are, with the exception of the very first sample, lower than during baseline conditions. This suggests a dilution effect of the water discharged at point 2, which normally had the highest concentrations of dissolved P.

7.2.11 Thermotolerant coliform bacteria

The coliform results, given in Figure 7.21, support the theory of different subcatchments having their first flush at different times, as two distinct clusters are seen. Clear decreases or increases are not visible, though. The numbers are dramatically high, in both groups, as well as at the individual sampling points when compared to the Bathing Water Directive (EC 78/160/EEC) as a convenient benchmark. The exception is point 2, where no thermotolerant

coliforms are present, as was the normal case during the baseline samplings as well. There is no certain explanation for these high values. Animal faeces are very unlikely to contribute to such enormous numbers. Speculations suggest that the source is a sewer overflow somewhere in the catchment that would bring untreated wastewater into the brook. It is unfortunate that a second storm sampling was not undertaken, which could verify these results. The coliforms present at points 4, 3 and 1 could be remnants from the sewer overflow. Animal sources are also possible, although the numbers are higher than almost all baseline values.

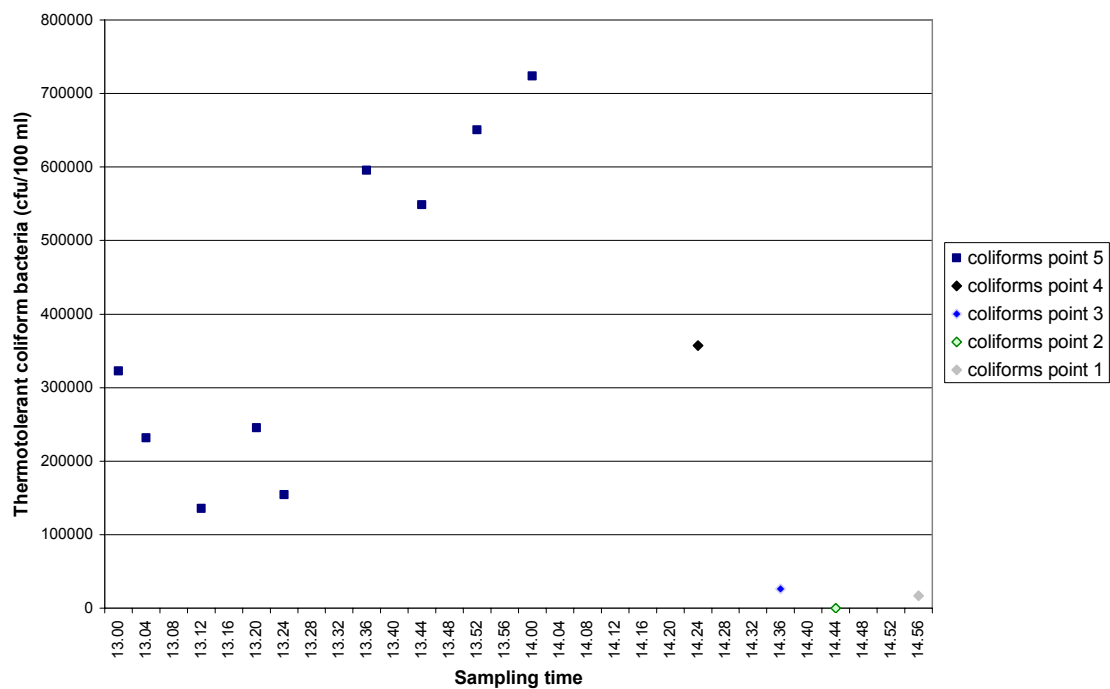


Figure 7.21 Thermotolerant coliform bacteria during storm at the different sampling points. The unit cfu stands for colony forming units.

7.2.12 The effects of urban runoff on the water quality

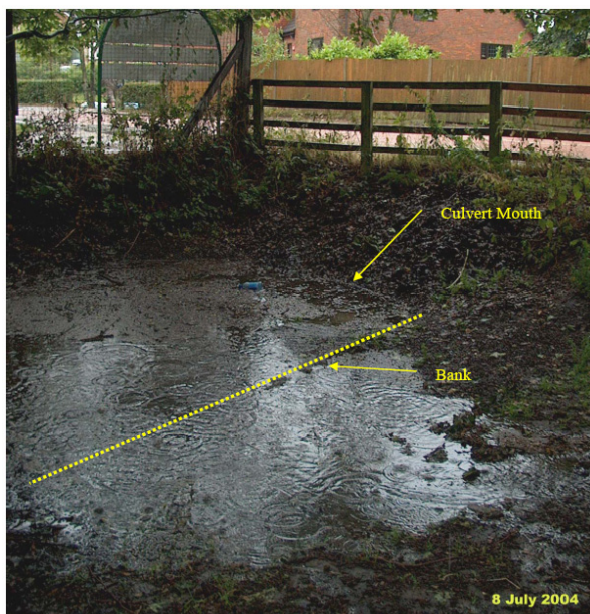
The pollutant concentrations were in most cases not exceptionally high, compared to other studies. The exception is the thermotolerant coliforms. This is one interesting finding from the storm analysis, the other one is the presence of subcatchments with different response times. These findings will be discussed along with the high flows in this section. The results are drawn from only one sampling, which makes them subject to uncertainties. More samplings to verify the results are of course necessary.

The thermotolerant coliforms were surprisingly high in number, without a satisfactory explanation, however, a sewer overflow seems a possible reason. The coliforms pose a health risk to children playing in or near the water.

The theory of subcatchments with different response times to the rainfall is sensible and obvious from the results. A pattern was seen in many variables, where a decreasing tail from one first flush was soon followed by a first flush from another subcatchment. In the case with fats, oils and grease, the two observed first flushes were clearly different in concentrations, suggesting that the flushes came from subcatchments with different traffic load. Observations

of flows in tributary pipes at different times during a rainfall also support the theory. Different times of concentration¹, or travelling times, in different parts of the catchment consequently caused the flushes at different times, but this phenomenon has not been mentioned in any literature read prior to this thesis.

The response time to rain is generally short, this was also observed in Hess and Tyrrel (2004), and the peaks are thus also short-term, even though they occasionally are high. The flows also grow high during heavy storms. This was seen during the rainfall commencing while sampling at point 1. The prior rainfall had caused high and turbid flow, but this one even caused a flood on the footpath at Station Road, and the rain falling on Station Road flooded down on both sides of the road, since the gullies could not cope with the flow. This behaviour was also observed by Hess and Tyrrel (2004), see picture in Figure 7.22. When the footpath is flooded, it is not possible to see the concrete channel and supporting structures by the culvert, and accidents might happen.



(Source: Hess & Tyrrel, 2004)

Figure 7.22 Flooding on the footpath.

From an ecological point of view are aquatic communities at risk during these high flows. Only a short exposure to high flows and toxic pollution concentrations is necessary to kill aquatic organisms (Larm, 1994). High pollution concentrations seem not to be an issue in this catchment, but the high flows with turbid water might cause lethal conditions. A biological study of the water quality and the communities would show if this risk is present or not.

One measure for avoiding flooding is the implementation of sustainable urban drainage systems (SUDS). These also separate pollutants from the runoff, reducing the input to the watercourse. Permeable pavements are suitable for car parks, where pollutants are filtered out in the sub-base material that can be enclosed in an impermeable membrane. Attenuation of the flow can be achieved by an infiltration device with storage capacity, where pollutants are

¹ The time of concentration is the longest time it takes for water to travel from any point in the catchment to the outlet (Hess, 2005)

filtered out in the ground. Infiltration basins let water slowly infiltrate and are only temporarily wet. The probable drawback in this case is that the space needed cannot be obtained. Another infiltration structure is an infiltration trench with underground storage with coarse-material filled chambers, which slowly release the drainage water into the surrounding soil. Swales are a different type of SUD, where velocity is slowed down and particles filter out in a broad shallow vegetated channel (Tyson, 2004; CIRIA, 2001). The shortage of space is a complication at this site, and the possibility of the brook running dry during low flows due to infiltration of all water exists. Careful design suited for the prevalent conditions is therefore crucial for a successful system.

7.3 Sediment sampling

The results from the preliminary and the successive three samplings will be presented and discussed here.

7.3.1 Preliminary sediment sampling

The preliminary sediment sampling was undertaken in order to see how deep it was possible to sample, what the sediments looked like, and to classify the soil type. The profiles are summarised in Figure 7.23, and the sampling points are showed in Figure 6.1.

Sampling point:	1, before Lyme Road	2, before Council car park	3, before Station Road culvert	4, after Station Road culvert
Bed surface:	Sand & gravel	Sand	Leaves & plant debris	Decaying leaves
Depth of core:	18-20 cm	25 cm	35 cm	30 cm
Core character: Depth (cm)	<div>0</div> <div>Loamy sand – sand, with gravel and decaying plant debris</div> <div>10</div> <div>Sandy loam with small stones and more sand than below</div> <div>Sandy loam with some small stones</div> <div>20</div> <div></div> <div>30</div> <div></div>	<div>0</div> <div>Sand with decaying plant debris and some small stones</div> <div>10</div> <div></div> <div>20</div> <div></div> <div>30</div> <div></div>	<div>0</div> <div>Loamy sand, some decaying plant debris</div> <div>10</div> <div></div> <div>20</div> <div>Sandy clay loam, with decaying plant debris</div> <div>30</div> <div>Loamy sand with decaying plant debris</div> <div></div> <div>Loamy sand with decaying plant debris</div> <div>Sandy loam with decaying plant debris</div>	<div>0</div> <div>Mainly sandy loam with some decaying plant debris</div> <div>10</div> <div></div> <div>20</div> <div>Loamy sand – sandy loam with decaying plant debris</div> <div>30</div> <div></div> <div>Sandy loam with some decaying plant debris</div> <div></div>
Remarks:	Difficult to sample → shallow sample obtained. Clay found in successive sampling in 10-15 cm layer	Difficult to sample, since only sand	Much debris in deepest part → difficult to classify	Clay found in successive sampling in 10-15 cm layer

Figure 7.23 Summary of the preliminary sediment sampling.

7.3.2 Sediment samplings

The sediments were analysed for thermotolerant coliforms and total zinc, but as the coliforms were analysed prior to the zinc, those results ruled the course of events. The results from the first sampling showed no consistency in number of bacteria, neither in layer nor in depth. Two successive samplings were undertaken to verify the results, if a pattern was there or not. A pattern in depth was more important to examine, and would reveal some of the coliform behaviour in the sediment. The samplings were undertaken at points 1, 2 and 4, since point 3 was too difficult to draw samples from. The results from the three samplings are given in

Figure 7.24, and show no consistency between depths. No consistency was found between sampling points either, but results are not shown.

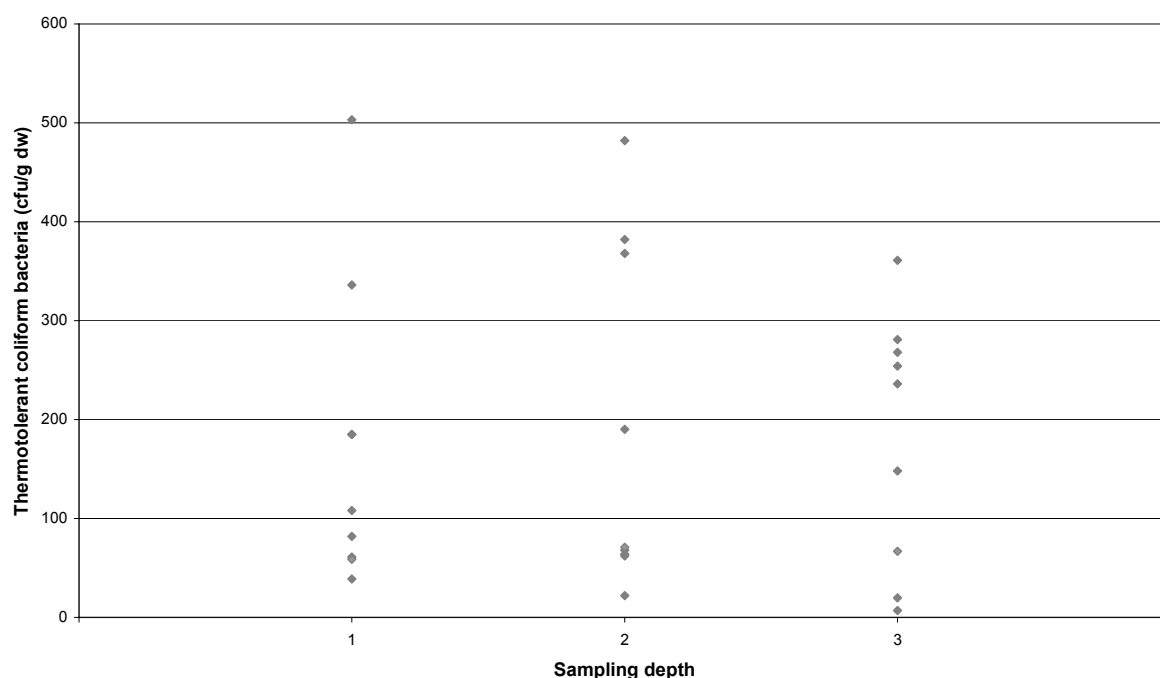


Figure 7.24 Thermotolerant coliform results from the three sediment samplings, given at the three depths per g dry sediment, where sampling depth 1 = 0-5 cm, depth 2 = 5-10 cm and depth 3 = 10-15 cm. Cfu stands for colony forming units.

The results vary between 7-500 cfu/g dry sediment, which is lower than expected, after seeing the numbers in the water. The fact that no trend was found, not even between the top and the lower layers, is surprising. The results were expected to be higher in the top layer, where most bacteria were thought to be dormant. An equalising effect might however hide this result, if high numbers of bacteria were present in the top cm of the top layer, and fewer in the remaining 4 cm, the average number in that layer is medium high. This does however not explain the bacteria present in the deeper layers, and how they get there. Coliforms live in sediments for 3-6 months and are to some extent motile (Tyrrel, 2005, pers com), but it is questionable if they would move so deep, and the reason for doing it. Sediment can of course settle on them on the river bed, but changes of up to 10-15 cm in the sediment layers cannot occur in this time interval in this watercourse. The transport of the bacteria down into the sediment is therefore mysterious, as is the reason for them to go there, if they move by themselves.

The zinc results are shown in Figure 7.25 and trendlines suggest an increase in concentration with depth. The trend is not statistically certain, but trendlines for the different series (each series is the three samplings at a specific point and depth) show an increase in 7 out of 9 cases, where each series makes a trend. The reason for the increase might be accumulation by settling sediment with associated zinc on the river bed. Resuspension can then sometimes change the sedimentation pattern, which might be the case at some points, even though large reorganisation of the sediment load is unlikely in this small stream. The small differences cannot be associated with soil type in the sediments either. Finer particles with higher specific

surface can bind more positively charged compounds, but since almost all of the sediment samples consisted of loamy sand and sandy loam, no discernment can be made. The zinc content in the sediment was expected to be low, especially since the water held such low concentrations. The sediment levels were however higher. Comparisons can be made with a study by Hayes and Buckney (1998), where sediments in two urban streams in residential catchments and a reference undisturbed stream were examined. The first stream had a stormwater drain outlet just upstream one of the three sampling points, where the Zn-concentration was 116 mg/kg, compared to 43.8 and 52.3 mg/kg for the two other points. The other stream had on average 27.8 mg/kg and the reference stream had 2.1 mg/kg. The sediment in the Sweetbriar Brook had concentrations of 30-152 mg/kg, on average 61.6 mg/kg. This is still not very high; Hayes *et al* (1998) discovered Zn-levels of 227-1472 mg/kg close to Sydney, which was considered high indeed. The possible sources are many, and can therefore not be specified.

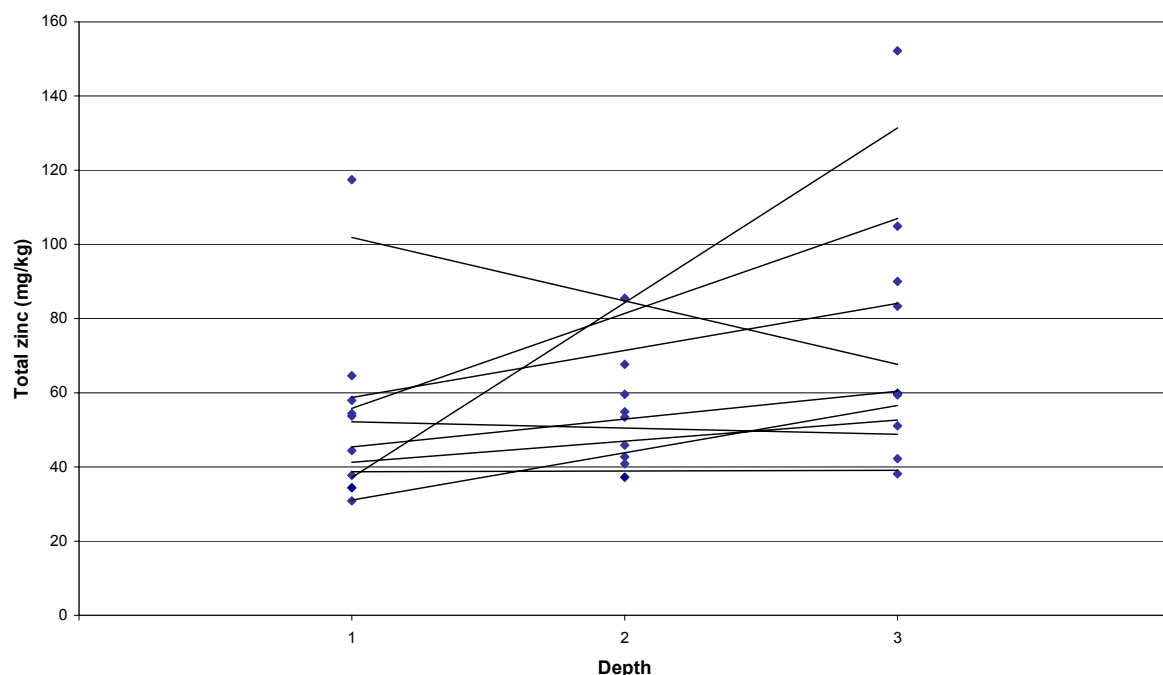


Figure 7.25 Total zinc from the three sediment samplings, given at the three depths per kg air dry sediment, where sampling depth 1 = 0-5 cm, depth 2 = 5-10 cm and depth 3 = 10-15 cm.

7.3.3 Overview of the sediment quality

The sediment quality cannot be determined from analyses of only thermotolerant coliform bacteria and total zinc, but an indication can be given. This indication reveals relatively low coliform concentrations throughout the sediment layers. It is though surprising how the bacteria end up in the deeper layers; by movement or settlement with covering sedimentation. The concentrations were also thought to be higher in the top layer, especially since the concentrations in the water sometimes are very high, both during normal conditions and storms.

The Zn-concentrations show a consistent pattern with higher concentrations with depth, possibly due to accumulation with settling sediment, having zinc associated to it. The soil

types in the sediment could however not explain the pattern, since there were no obvious differences in soil types with depths. The concentrations were relatively high, but any specific source cannot be pointed out, since zinc is a common element in the built environment.

The sediment samplings were undertaken during dry weather, as for the baseline water samples, at least three days of dry weather was required, not to cause interferences. Samplings close after rainfall was planned to be done, but the project was scaled down due to time shortage. No study of rainfall addition of zinc and the comparison to dry weather load could therefore be made.

8 CONCLUSIONS

The conclusions concern the baseline water quality, the storm sampling and results, the sediment analysis, and the study as a whole.

The baseline study revealed:

- The water quality is generally good, but occasionally has high numbers of thermotolerant coliform bacteria, that can pose a health risk to children playing in the water.
- Anaerobic zones are believed to be formed in the standing water before the Station Road culvert, where metals dissolve and become more bioavailable. This conclusion is supported by lower pH in the standing water.
- The stream is eutrophic, especially phosphorus values are very high.

The storm sampling showed:

- The character of the runoff was not clearly linked to traffic with its related pollutants, even though higher concentrations of almost all variables tested showed more polluted water in the stream during storm.
- Exceptionally high numbers of thermotolerant coliforms occurred during the sampled storm, with a sewer overflow as a possible cause.
- The catchment can be divided into subcatchments which contribute with individual peaks of pollutants during the storm, i.e. there is not one first flush bringing the vast amount of pollution, but several smaller ones.
- Storms can cause high flows that back up before the Station Road culvert, flooding the footpath. This poses a health and safety risk as both the path and the culvert structure are under water and not visible. Another risk is the direct access playing children have to the bacteria-containing stormwater.
- A sustainable urban drainage system (SUDS) should be implemented before the culvert to prevent flooding to occur.
- Only one storm was sampled, the results cannot be applied to all storms. This storm had a long antecedent dry period, allowing more pollutants to accumulate on the hard surfaces. The intensity of the rainfall also is important for the ability to detach the pollutants from the surfaces.
- The sampling should ideally have lasted for a longer time, to catch more of the first flushes from the different subcatchments. This would help to verify and refine this theory.

The sediment study demonstrated:

- The thermotolerant coliforms are relatively few, and vary in depth. The depth variation cannot be satisfactorily explained.
- The zinc concentrations are relatively high, with a pattern of increase with depth. The sources are not specified.
- More information is needed, both by extension of the undertaken samplings and from new analyses, both chemical and biological.

General conclusions are:

- With the exception of thermotolerant coliforms, no very high concentrations of pollutants studied were found. Small streams like this one shall however not be neglected as a carrier of pollutants. The inputs should be reduced and the health risks considered, together with the flood risks.

- No statistics were used in the analyses of the results, only consistent trends can be observed. This is a shortage of the study, but several variables and different sampling points were prioritised over many replicates. Long-term monitoring and statistical analysis should be used in forthcoming samplings to verify the results found in this study.
- This thesis contributes with information on the water quality in a stream in a small urban, mainly residential catchment. The effects of stormwater runoff are noticeable although not dramatic, with the exception of thermotolerant coliforms.

9 RECOMMENDATIONS

From the results the following recommendations are given:

- To collect more information on the water quality and the impacts of runoff, a monitoring programme should be developed, both for baseline and storm conditions. Parameters to include are, together with the ones chosen for this study, suspended solids, particulate phosphorus and some organic pollutant. Several storms should be sampled during longer times and during different parts of the year with varying antecedent dry and wet conditions. The flows should also be recorded. Several sampling points are desirable, to determine the contributions from different parts of the catchment.
- The sediment analysis should also be extended, both with chemical and biological parameters. Different particle-bound compounds, such as phosphates and some organic pollutant should be added, together with oil. The biological monitoring should comprise some macroinvertebrate analysis. These can give a good indication of the general water quality.
- A monitoring programme of some kind will probably be necessary with the implementation of the EU Water Framework Directive (WFD), of which the aim is good status in all waters. Biological monitoring will for example be one component in the requirements for the directive.
- The inputs of pollutants, especially thermotolerant coliforms, should be investigated and reduced for health reasons.
- The water should be kept aerated, not to cause anaerobic zones with conditions allowing metals to dissolve into more toxic forms. This can be achieved by keeping the weed screen at the Station Road culvert clear of debris.
- Regular cleaning of the weed screen also prevents water from backing up and flooding the footpath.
- Another measure for avoiding floods is the implementation of sustainable urban drainage systems (SUDS), such as permeable pavements on the car parks and an infiltration device or a swale along the brook before the culvert.

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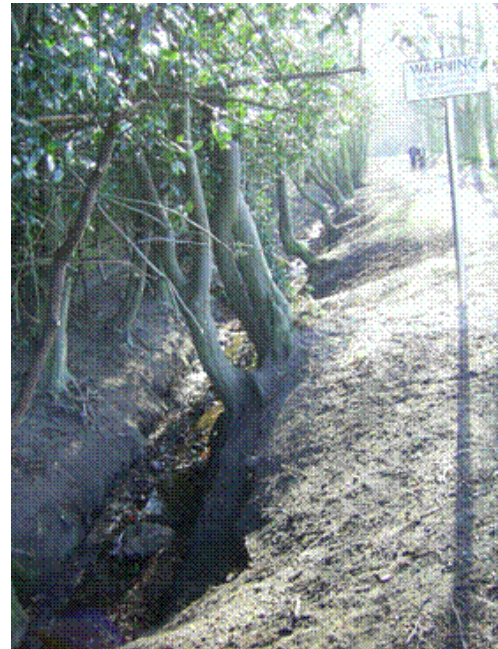
APPENDICES

Appendix A

Photos of the Sweetbriar Brook and the sampling points for water analyses



Sampling point 1: the headwall pipes with a continuous, although small, flow in the lower pipe



Downstream view from sampling point 2



Sampling point 2: 1st tributary pipe with a continuous flow (right pipe on the picture)



Lyme Road
tributary
(left)



Sampling point
3: Lyme Road,
downstream
view (right)



Outlet
from
Council
car P
(left)

Around
sampling
point 4: After
Council
car P,
downstream
view (right)



Station
Road culvert
(left)

Sampling point
5: After Station
Road culvert
(right)



Appendix B

Results from baseline samplings

Table B1 Results from baseline samplings

Parameter	pH	temperature (deg C)	conductivity (mS/cm)	DO (mg/l)	DO (%)	turbidity (FTU)	tot-Fe (mg/l)
Sampling 1							
12.04.05							
Sampling point							
1. Start	7.8	9.8	0.912	9.1	74	6	0.26
2. 1st pipe	7.5	10.0	0.928	10.2	85	0	0.05
3. After Lyme Rd	7.6	9.8	0.913	9.8	87	4	0.11
4. After Council car P	7.4	9.4	0.896	9.57	89	14	0.28
5. After Station Rd culvert	6.9	8.8	0.907	8.85	84	10	0.27
Sampling 2							
31.05.05							
Sampling point							
1. Start	7.8	11.6	0.984			8	0.30
2. 1st pipe	7.7	13.3	0.910			0	0.04
3. After Lyme Rd	7.9	12.6	0.881			10	0.25
4. After Council car P	7.5	13.6	0.863			18	0.42
5. After Station Rd culvert	6.7	15.4	0.828			19	1.38
Sampling 3							
22.06.05							
Sampling point							
1. Start	7.5	13.7	0.769			63	4.8
2. 1st pipe	7.5	16.2	0.733			2	0.04
3. After Lyme Rd	7.9	16.8	0.713			17	0.46
4. After Council car P	7.7	18.8	0.750			27	0.51
5. After Station Rd culvert	7.3	16.4	0.858			26	1.86
Sampling 4							
12.07.05							
Sampling point							
1. Start	7.3	13.8	0.769			18	1.2
2. 1st pipe	6.9	16.5	0.686	9.07		1	0.05
3. After Lyme Rd	7.6	16.3	0.684	6.77	62	8	0.28
4. After Council car P	7.5	18.4	0.722	7.04	72	21	0.58
5. After Station Rd culvert	6.5	16.4	0.610	3.24	32	23	1.77
Sampling 5							
02.08.05							
Sampling point							
1. Start	7.1	14.9	0.749	8.13	81	19	1.94
2. 1st pipe	7.1	16.4	0.706	7.58	79	2	0.09
3. After Lyme Rd	7.8	16.2	0.694	9.28	96	8	0.24
4. After Council car P	7.6	17.0	0.706	7.31	76	25	0.66
5. After Station Rd culvert	7.0	16.0	0.675	4.1	42	20	2.22

Table B1 continues on the next page

Table B1 Results from baseline samplings, continued

Parameter	BOD (mg/l)	total solids (mg/l)	tot-N (mg/l)	tot-P (mg/l)	FOG (mg/l)	tot-Zn (mg/l)	coliforms (cfu/100 ml)
Sampling 1							
12.04.05							
Sampling point							
1. Start	1.155	0.582	6.3	0	0.48	0.028	685
2. 1st pipe	1.16	0.562	6.9	0.6	0.68	0.018	0
3. After Lyme Rd	1.450	0.536	6.1	0.2	1.16	0.014	36
4. After Council car P	1.515	0.454	5.5	0.1	1.12	0.025	100
5. After Station Rd culvert	0.855	0.464	5.6	0.1	0.46	0.021	403
Sampling 2							
31.05.05							
Sampling point							
1. Start	1.220	0.622	6.3	0	0.07	0.039	1105
2. 1st pipe	0.905	0.508	6.9	0.5	0.37	0.026	0
3. After Lyme Rd	1.335	0.624	6.0	0.4	1.76	0.028	280
4. After Council car P	1.520	0.598	6.0	0.2	0	0.037	417
5. After Station Rd culvert	1.315	0.552	4.8	0	0.10	0.024	403
Sampling 3							
22.06.05							
Sampling point							
1. Start	5.275	1.516	7.5	0	1.38	0.014	322
2. 1st pipe	0.990	0.726	6.6	0.1	4.28	0.017	0
3. After Lyme Rd	1.295	0.714	6.2	0.1	0	0.016	2100
4. After Council car P	3.050	0.712	5.7	0	1.83	0.016	10950
5. After Station Rd culvert	2.140	0.726	4.4	0	0	0.017	950
Sampling 4							
12.07.05							
Sampling point							
1. Start	2.415	0.678	7.6	0	0.12	0.017	265
2. 1st pipe	1.460	0.556	5.2	0.1	0	0.021	0
3. After Lyme Rd	1.130	0.582	5.5	0.1	0.17	0.016	44050
4. After Council car P	2.025	0.580	4.6	0	0	0.014	16100
5. After Station Rd culvert	1.530	0.562	3.9	0	0.07	0.015	6550
Sampling 5							
02.08.05							
Sampling point							
1. Start		0.528	6.7	0	1.64	0.031	1770
2. 1st pipe		0.478	5.4	0.2	1.20	0.015	0
3. After Lyme Rd		0.292	5.4	0.2	1.55	0.012	1470
4. After Council car P		0.524	4.5	0.1	2.38	0.009	1565
5. After Station Rd culvert		0.530	3.5	0	1.32	0.036	343

Appendix C

Results from storm sampling

Table C 1 Results from storm sampling

Storm sampling	Parameter	pH	temperature (deg C)	conductivity (mS/cm)	DO (mg/l)	DO (%)	turbidity (FTU)	tot-Fe (mg/l)	BOD (mg/l)	total solids (mg/l)	tot-N (mg/l)	tot-P (mg/l)	FOG (mg/l)	tot-Zn (mg/l)	thermotolerant coliforms (cfu/100 ml)
Sampling date	22.06.05														
Sampling point	Sampling time														
5	13.00			0.356		60.1	241	2.52	5.255	0.600	4.4	0.6	2.58	0.078	322 500
5	13.04			0.373	3.21	43.7	179	0.84	5.555	0.502	5.1	0.1	4.65	0.058	231 500
5	13.08			0.347			172	0.82	6.090	0.622	4.9	0	0.61	0.017	
5	13.12	7.2		0.336	5.40	58.7	122	0.88	6.040	0.508	5.4	0	4.79	0.036	135 500
5	13.16	7.4	22.9		5.52	61.6			5.880						
5	13.20	7.3	21.6	0.300	5.86	63.8	120	2.66	6.725	0.396	5.8	0	0.11	0.048	245 500
5	13.24	7.5	19.7	0.299	6.37	67.8	167	5.74	6.310	0.476	5.0	0	0.60	0.037	154 500
5	13.28	7.6	19.2	0.356	6.53	68.9	204	6.00	6.450	0.586	5.1	0	0	0.033	
5	13.32	7.5	18.7	0.444	6.70	69.4	238	6.00	6.325	0.824			0.25	0.040	
5	13.36	7.5	19.1	0.418	6.74	69.7	245	5.92	6.230	0.680	5.6	0.1	0	0.046	595 500
5	13.40	7.5	19.2	0.378	6.77	69.9	238	3.84	6.195	0.596	5.7	0.1	0.62	0.029	
5	13.44	7.5	20.2	0.336	6.83	70.6	230	6.08	6.380	0.448	4.7	0	0.70	0.023	548 500
5	13.48	7.4	19.4	0.309	6.77	70.3	202	5.98	6.360	0.386			0.40	0.037	
5	13.52	7.3	19.3	0.297	6.75	70.1	184	4.30	6.610	0.464	6.2	0	0.52	0.029	650 500
5	13.56	7.2	19.4	0.280	6.73	69.9	165	4.64	6.460	0.422	6.1	0	0.12	0.051	
5	14.00	7.3	19.4	0.273	6.58	68.7	158	3.64	6.570	0.364	5.5	0	0.15	0.101	724 000
1	14.55	7.1		0.425			37	0.46	7.715	0.350	5.3	0.1	0	0.250	16 750
2	14.45	7.3	17.3	0.830	4.59	47.9	0	0.08	0.795	0.594	4.0	0.1	0.20	0.091	0
3	14.35	7.5	17.8	0.551	3.84	41.9	55	1.18	7.940	0.454	5.3	0	6.25	0.015	26 000
4	14.25	7.6	19.2	0.257	4.67	50.0	110	2.75	6.445	0.296	5.5	0.1	1.58	0.027	357 000

Appendix D

Results from sediment samplings

Table D.1 Thermotolerant coliform bacteria in sediment samples, given as cfu/g dw (where cfu stands for colony forming units)

Sampling point	1 (Lyme Rd)	2 (Before Council car P)	4 (After Station Rd)	
Depth				
1 (0-5 cm)	185	61	39	Sampling 1
	82	336	108	Sampling 2
	185	503	59	Sampling 3
2 (5-10 cm)	190	64	22	Sampling 1
	482	382	62	Sampling 2
	68	368	71	Sampling 3
3 (10-15 cm)	281	7	254	Sampling 1
	148	236	20	Sampling 2
	268	361	67	Sampling 3

Table D.2 Total zinc in sediment samples, given as mg/kg air dry weight

Sampling point	1 (Lyme Rd)	2 (Before Council car P)	4 (After Station Rd)	
Depth				
1 (0-5 cm)	34.4	30.9	37.7	Sampling 1
	57.9	44.4	53.7	Sampling 2
	64.6	117.5	54.4	Sampling 3
2 (5-10 cm)	37.3	67.6	40.9	Sampling 1
	42.7	54.9	85.5	Sampling 2
	59.6	53.4	45.9	Sampling 3
3 (10-15 cm)	59.9	42.3	38.1	Sampling 1
	152.2	59.4	104.9	Sampling 2
	90	83.3	51.1	Sampling 3

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